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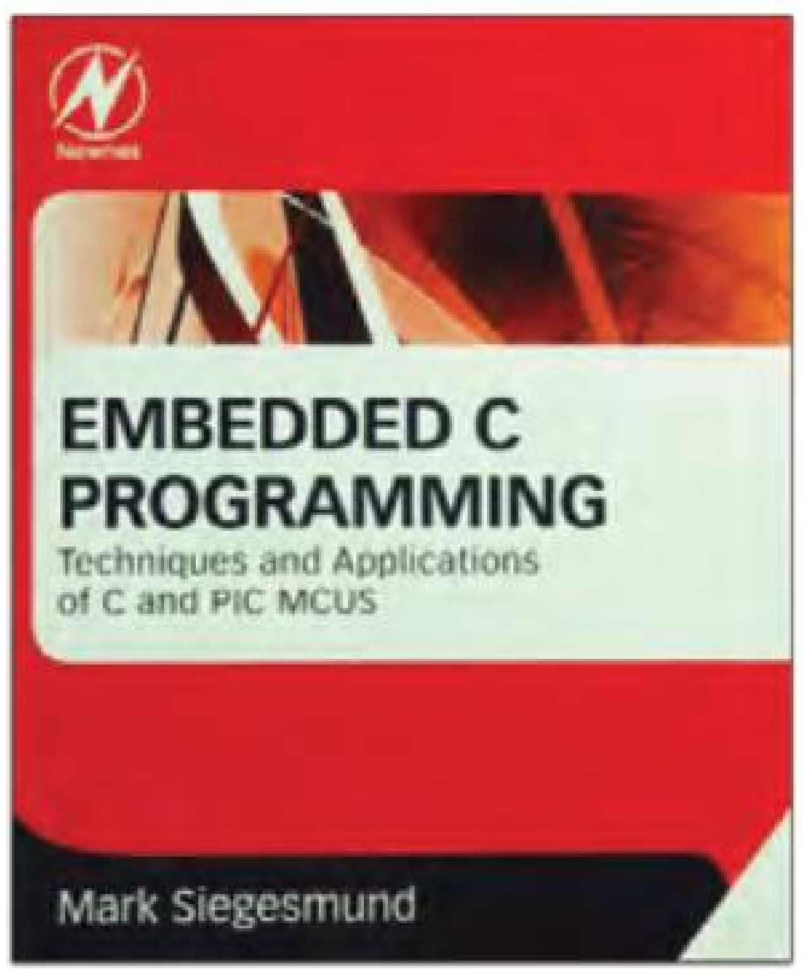

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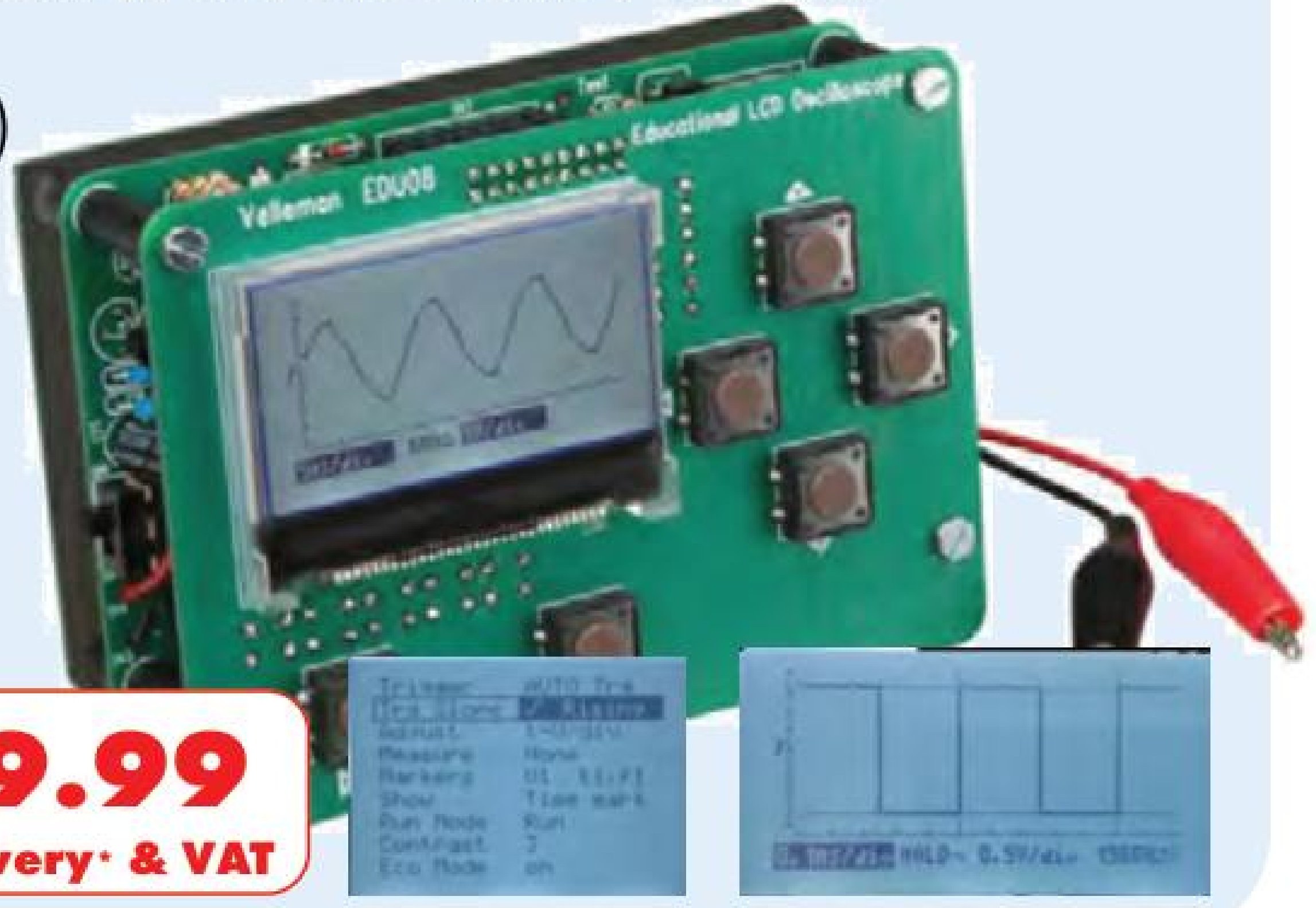

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We advise readers that certain items of radio transmitting and telephone equipment which may be advertised in our pages cannot be legally used in the UK. Readers should check the law before buying any transmitting or telephone equipment, as a fine, confiscation of equipment and/or imprisonment can result from illegal use or ownership. The laws vary from country to country; readers should check local laws.

Projects for every interest!

We have a particularly fine line up of projects for you to read over the Christmas period as you digest your turkey. To avoid the inevitable round of disappointing TV repeats, why not settle down with your favourite electronics magazine – or, better still, switch on the soldering iron and make something useful, interesting or simply fun!

Following the excellent *Currawong Stereo Valve Amplifier* from just over a year ago, we have stayed on the thermionic audio path with a *High-performance Stereo Valve Preamplifier*. It boasts very low distortion, excellent noise figures and runs off low-voltage DC supply. Its smart transparent case means it looks the part too.

Next up is a magnificent *6-Digit LED GPS Clock* that not only knows what time it is, but also knows what time zone it inhabits and even what local daylight saving protocol is in place. Plus, it includes an alarm, a timer and a real wow factor thanks to its impressively large seven-segment displays.

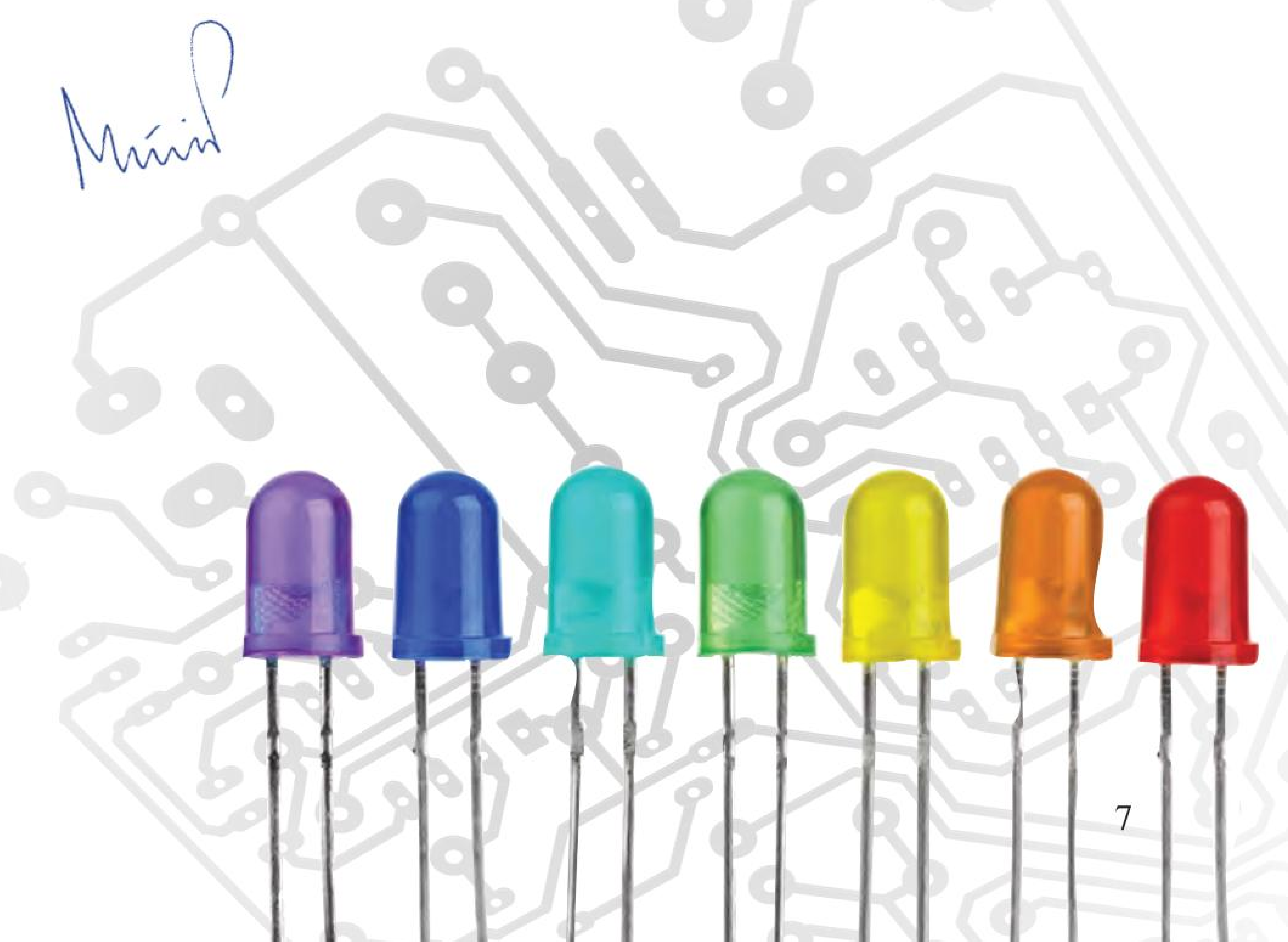
Last, but not least, for lovers of DAB radio we have a truly rewarding antenna design that will help you get the most from your digital radio investment.

All this and our regular columns means you'll have plenty to read and enjoy this Christmas.

Missing *Teach-In*?

If, like me, you have been avidly following Mike and Richard Tooley's excellent *Teach-In* articles on the Arduino then you'll be sorry that this issue marks the conclusion of that particular series. I certainly learned a great deal and I hope you were inspired to use it in your designs and projects. So, the obvious question for future issues is how do we fill a *Teach-In*-shaped hole in the magazine? Well, it won't be easy, but I think we have come up with just the thing if you're a fan of 32-bit PIC microcontrollers, the BASIC language and not spending a fortune on small, but powerful devices. I'm not going to spoil the surprise with any more details; all will be revealed in the very next issue!

It only remains for me, along with all the team at *EPE*, to wish our readers a very happy Christmas and a solder-themed New Year.



NEWS

A roundup of the latest Everyday News from the world of electronics

VR motion sickness and malware – report *by Barry Fox*

Each new technology brings new problems for users – often without warnings.

It was only after 3D TV had been launched that the manufacturers started to issue health warnings about eye/brain discomfort. We can now expect similarly late warnings that VR (virtual reality) can cause motion sickness.

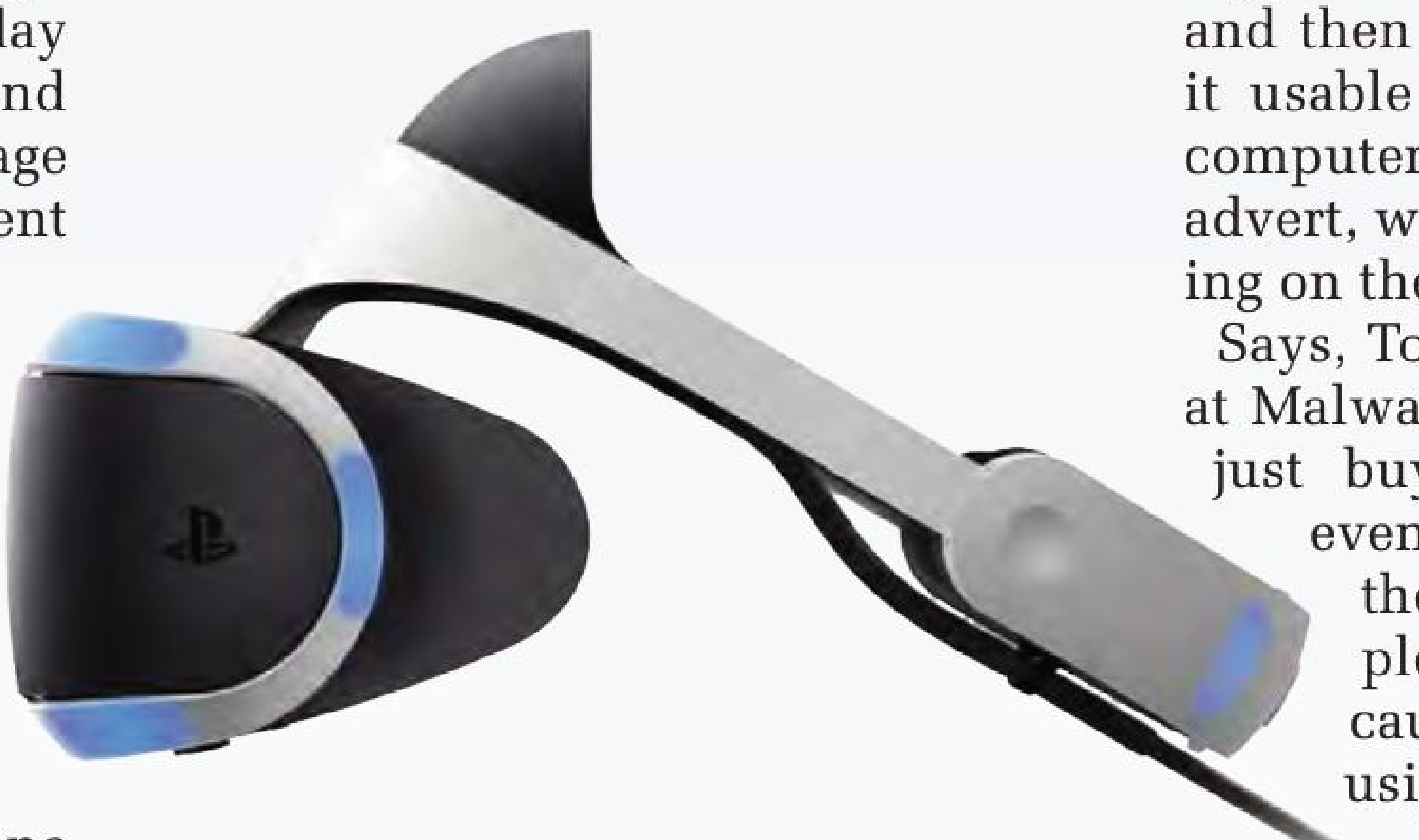
Patents show that the industry has known about VR side effects for – literally – decades. Most recently, Sony's US patent filing 2016/0246057, published under the none-too-informative title 'Image Display Device and Image Display Method, Image Output Device and Image Output Method, and Image Display System', reveals the extent of industry awareness.

'Head-mounted displays are extremely popular' Sony wrote in 2014, when the patent was filed, 'if mass production advances further in the future, head-mounted displays may become as common as mobile phones, smartphones, or handheld game consoles, and everyone may come to own their own head-mounted display.

'The causes of VR sickness are various' the patent further explains, '…when an image with a wide range provided by an image output device is viewed over a narrow field on the side of the image display device or when an image with a narrow range provided by an image output device is viewed over a wide field on the side of the image display device, distortion remains and readily induces VR sickness.'

Sony's aim is 'reducing VR sickness …(by) correcting the mismatch between the field of view of the provided image and the field of view experienced by the viewer.'

Each user personalises their head mount viewer, with the result stored in standard format Extended Display Identification Data (EDID). The head mount then automatically tailors all VR images it displays. When the field of view of the VR image is too large the device cuts out and displays only a central region; when the VR field of view is smaller, the display adds black margins or wallpaper to fill the edge gaps, or stretches the images to fit. Either way, the field of view of the VR images matches the user's field of view.



Sony's Playstation VR headset – the gaming giant is aiming to fix VR motion sickness

As a result, 'it is possible to greatly reduced VR sickness in the user (and) it is possible to display images from the first-person view or images with a wide field of view while reducing VR sickness.'

Will companies selling VR now promote them with the promise of less sickness than from competitors' headsets?

Banner alert

Every day brings news of a new Internet hack, or DDS (distributed denial of service) attack on a major website caused by malware on home computers around the world stealthily forcing them all to send query messages to the same target site at the same time. The latest attack was possible because the new breed of Internet of Things devices, like cameras and toasters, are being sold without adequate malware protection.

Internet security company Malwarebytes (which offers excellent free software for scanning a computer to find and fix computer infections) has now warned of a new threat. Ransomware, which encrypts all the data on a computer and then demands money to make it usable again, can now infect a computer from a website banner advert, without the user even clicking on the banner.

Says, Tom Dell, Channel Manager at Malwarebytes: 'The hackers can just buy advertising space and even if the infected banner is then taken down, some people will already have been caught. The hackers are now using different encryption keys for different files, so there is no hope of getting the data back without the full set of keys the hackers are offering to sell. For a business it's a simple choice – pay the random or lose the data. One small company just shut up shop, sent all its staff home and went out of business. Even if the company has made system backups, they will also be infected and just re-encrypt the restored data'.

Malwarebytes claims a feature of its new (paid for) software called Anti-Exploit protects against Ransomware. Another approach is for anyone with valuable data to make regular backup copies of the data on its own, rather than as part of a full system backup.

VR motion sickness and malware *continued*

Does O2 care about customer protection?

Recently, I received a text message, apparently from O2 Billing, addressing me by name, and warning 'We're having trouble verifying the information linked to your O2 account. Click below to avoid services being suspended'. The link led to what looked like the O2 Billing website and asked me to confirm my account details.

Playing safe, I took the phone to an O2 store whose staff put me through to an O2 Helpline – who brushed off with 'we didn't send that text so it is nothing to do with us'.

Now, and only because I persisted by asking O2 for press comment on O2's failure to take a report of attempted fraud on O2 subscribers seriously, a spokesman says: 'Our Fraud and Security have investigated and this is a result of smishing – spam texting. The team have taken action to block the sender of these fraudulent SMS messages and they have made a request to the domain host to have the fraudulent website taken down'.

'The team will also alert any other O2 customer who may have received this message so that they can take action to protect themselves', says O2.

But just how O2 is warning other customers of this new and cleverly implemented scam is so far unclear.

DARPA aims for zero-power tactical sensors

There's efficient, there's low-power, but what about zero-power electronics? In the US, DARPA (Defense Advanced Research Projects Agency) is working on electronic systems that use so little power that they can harvest what they need from the environment.

DARPA's Near Zero Power RF and Sensor Operations (N-ZERO) is developing technologies for sensors that can remain dormant, with near-zero power consumption, until awakened by an external trigger or stimulus such as the acoustic signature of a particular vehicle or radio communications protocol. If successful, the program could extend the lifetime of remotely deployed communications and environmental sensors – known as unattended ground sensors (UGS) – from weeks or months to years.

State-of-the-art military sensors rely on 'active electronics' to detect vibration, light or other signals for situational awareness and tactical planning. That means the sensors constantly consume power, with much of that power spent processing what often turns out to be irrelevant data. This power drain limits sensors' useful lifetimes to a few weeks or months with even the best batteries. The chronic need to service or redeploy power-depleted sensors is not only costly and time-consuming but also increases military personnel exposure to danger, or as Dr Roy Olsson, N-ZERO's programme manager put it – 'In combat situations we can't endanger solders just to replace batteries'.

N-ZERO will initially focus on two broad areas. One looks at UGS capable of continuous monitoring for infrequent events, with near-zero power consumption, but that activate a conventional sensor suite for further sensor data collection and processing when an event of interest is detected. Only then would significant power be drawn. The other broad area concentrates on radio receivers that are continuously alert for friendly radio transmissions, but with near-zero power consumption when transmissions are not present. A common feature of both focus areas is that the sensing is continuous; no events of interest are missed.

The N-ZERO programme is exploiting the energy in the signal signature itself to detect and discriminate the events of interest while rejecting noise and interference. 'We want the signals themselves to actually power the processing before waking up a more powerful signal-processor and transmitter,' said Olsson.

This requires the development of passive or event-powered sensors and signal-processing circuitry. The successful development of these techniques and components could enable deployments of sensors that can remain 'off' (in a state that does not consume battery power), yet alert for detecting signatures of interest, resulting in greatly extended durations of operation.

The DARPA researchers have found that ultra-low-energy design was impossible without using micro-electro-mechanical systems (MEMS), which provides not just near-zero standby power, but can be configured for absolute zero standby power by using the power from the signal to be detected itself to power-up the transmitter. And in some situations, the transmitter too can be powered without a battery, by storing up energy on a super-capacitor from renewable sources via solar and vibrational

Brontobyte

A recent *EE Times* article on the likely effects of the IoT estimated that by 2025 a trillion sensors will be online in one form or another – that's over 100 for every human on the planet. But that number pales into insignificance compared to the amount of data that these sensors will generate – 1000 yottabytes. In fact, a new number has been created – half-jokingly called the 'brontobyte', named after the enormous dinosaur. One brontobyte is 1000 yottabytes, or one billion billion terabytes; a lot of disk space.

Meet the Pi-top

Fancy a Raspberry Pi laptop? If the latest portable from another fruity manufacturer, Apple, is just a bit too expensive then head over to **www.pi-top.com**. There you can purchase a kit to make a fully functioning laptop computer based on the Pi. For $299 you get a 1368 × 768 pixel LCD screen; a case with built-in keyboard; a 'PC hub' that takes care of power management and drives the screen; and of course a Raspberry Pi 3. According to the manufacturers, 'You can even replace its microprocessor when a new one comes out', thus keeping your laptop at the cutting edge of Pi-tech.

$1000 to change the world!

Element14 has launched an interesting competition calling for designers to submit ideas All you need to do is select $1000 worth of products from their range and explain in 500 words or less how you would use them to 'Change the World'.

The competition is simply about ideas; to enter, you don't need to buy or develop anything, just explain what products you need and how you would use them. 10 Winners will receive the $1000 worth of products – for further details, go to: **http://element14changetheworld.com**

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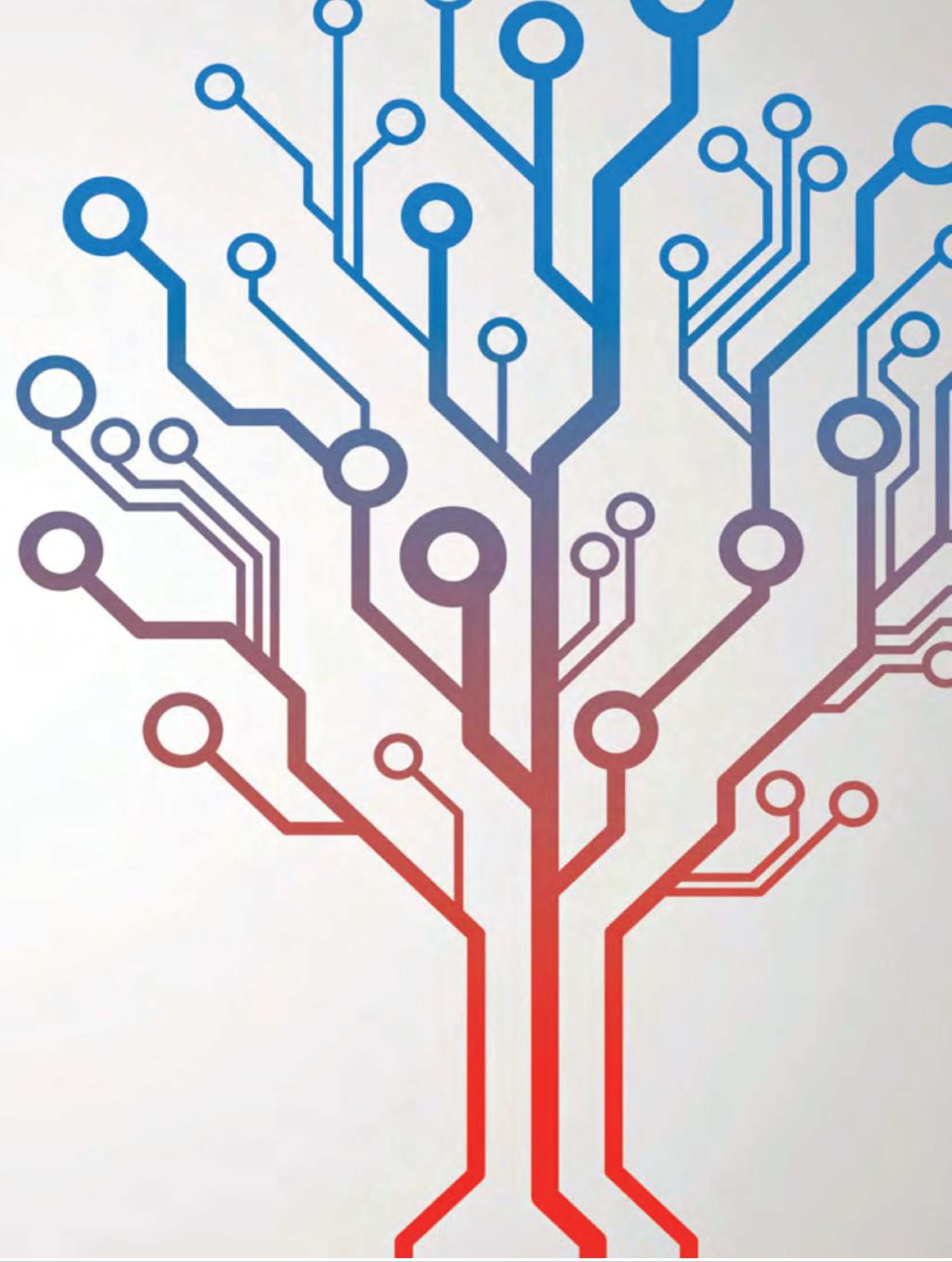

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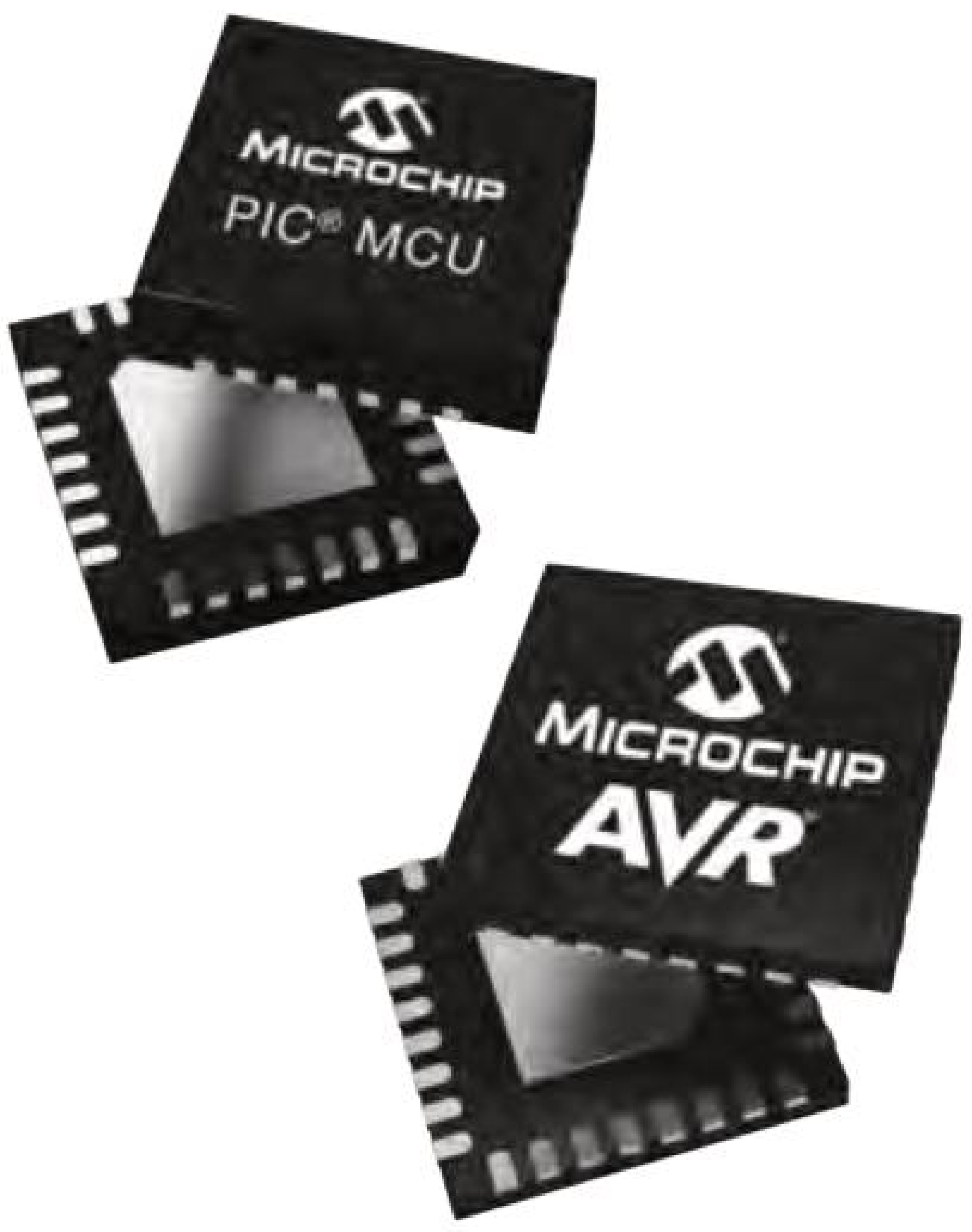

Key Features

- Autonomous peripherals
- Low-power performance
- Industry-leading robustness
- Easy development

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New year, new insights

TechnoTalk

Mark Nelson

With age comes wisdom (allegedly), so as we enter this New Year I offer you three nuggets of knowledge that I discovered recently and now feel obligated to share with you. Edification and amusement are both guaranteed, so lend me your eyeballs.

IT'S NOW OFFICIAL. CHANCELLOR Hammond has warned us of 'turbulent times' ahead as prices are already rising in anticipation of 'seizing the opportunities that the wider world has to offer' (his words, not mine). So, canny constructors must look for the best possible value for money when buying electronic components online.

Chinese cornucopia

Almost inevitably our eyes turn eastwards, because the best bargains on **eBay.co.uk** (and **AliExpress.com**, which has a far wider choice) come from China. If you choose carefully and are prepared to wait a month for your plunder to arrive by 'slow boat from China', you should get what you want at bargain basement prices. But does this mean that electronic components are intrinsically cheaper to buy in China? Actually no – allow me to explain...

At my local shopping centre we have an extremely well-patronised food shop that sells brand-name foods at fantastically cheap prices. Look closely and you will find that the 'eat by' date on most of their lines is only two weeks away. The shop buys in these products from wholesalers who specialise in 'short-dated' foodstuffs that are almost valueless to mainstream supermarkets.

In the same way, most of the Chinese components you buy online are almost valueless to manufacturers over there. What you are buying is over-runs and other surplus stocks that are just wasting warehouse space. Frequently, the dealers you buy from have no idea of what they are selling or how much it's worth, but you can be sure they are not making a loss by selling so cheap. An excellent 'In Business' programme on BBC Radio Four explains how the system works (listen at: **www.bbc.co.uk/programmes/b06pxt4c**). 'In some areas of rural China, traditional farming communities are transforming into something very 21st Century: Internet shopping hubs. Leading the way is the village of Qing Yan Liu where, four hours south of Shanghai, local residents have created a world of bubble wrap and sticky tape. In the eyes of the Chinese Premier Xi Jinping this could be the future of rural China. He hopes that more and more small communities will copy what's happened in Qing Yan Liu – now dubbed 'China's No. 1 e-Commerce village'. Turning more small towns and villages into online shopping hubs would provide much needed jobs, ensuring communities continue to survive rather than disappear.'

Upgrade your Hi-Fi the non-technical way!

As regular readers will know, every now and again I take a gentle pop against audiophools, those Hi-Fi addicts who genuinely believe that the more you spend on your music system, the better it will sound. So here's my latest audiophool alert, which concerns 'tuning dots'. Never heard of them? Nor had I until I was tipped off...

Up till now, I assumed that the quest for supreme audiophile ecstasy lay in cables made of organic copper with all the crystals aligned in one direction and in the use of 13A mains plugs fitted with rhodium-plated pins. Turns out I was wrong; tuning dots are a far more significant determinant of ultimate musicality. Even better, you don't need a soldering iron, not even a screwdriver... you just stick a few of these magic dotlets over the auditory environment. But I won't keep you in suspense a moment longer; just visit **http://marigoaudio.com/tuning-dots/** and see for yourself. While you're about it, check out their titanium power cables and 'mystery feet'. Naturally these dots are not cheap ($159 for a set of eight) and you have to order them from the States. Fortunately, I have managed to track down a supplier here in Britain, so I commend you to save money and try these ones first: **www.ebay.co.uk/itm/162096052881**

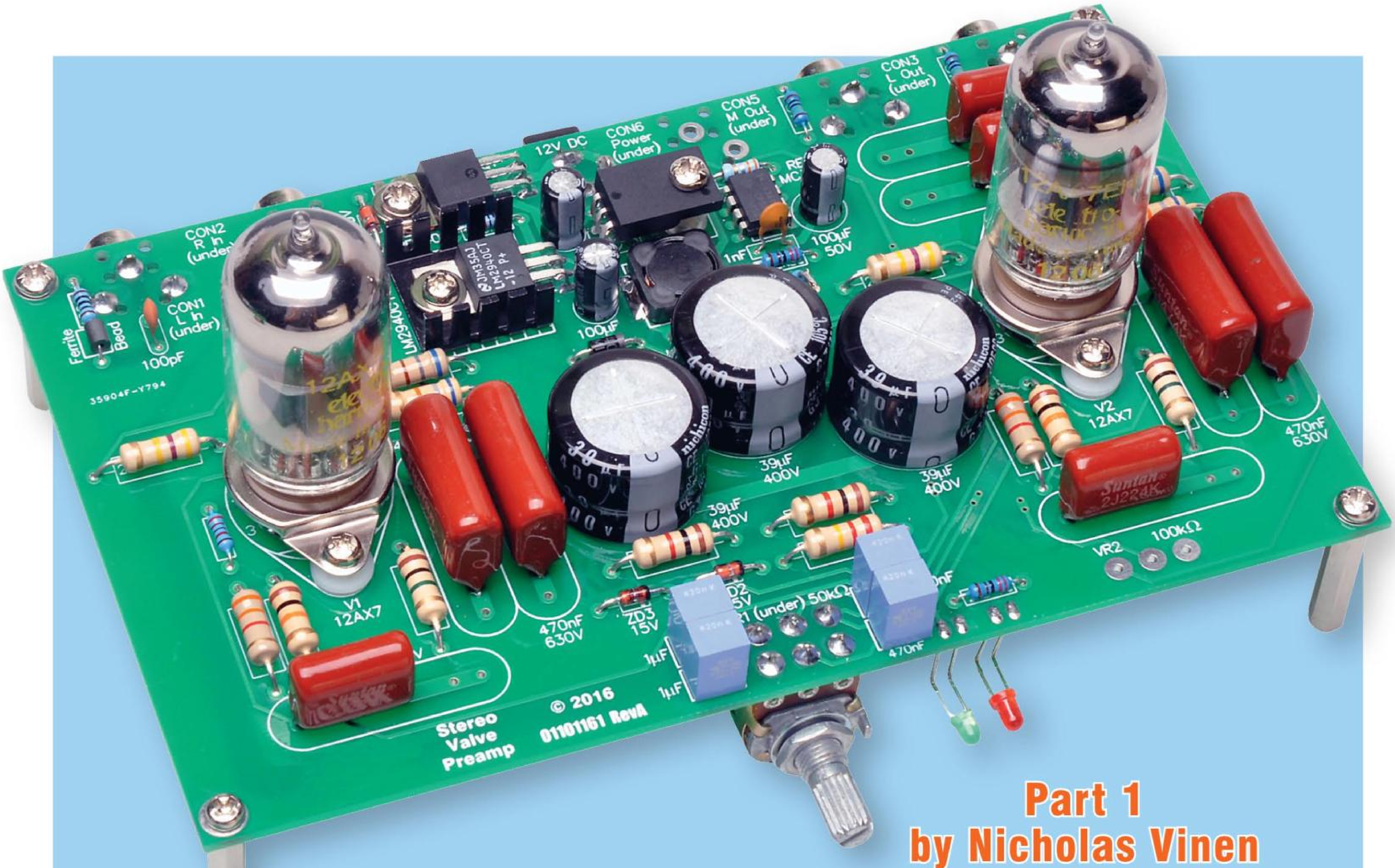
Vindicated!

That's how the organisation GPEN – Global Privacy Enforcement Network – must feel now after their prediction made last September has dramatically come true. At the time, its commissioner Daniel Therrien warned about the proliferation of the Internet of Things (IoT) and that there was significant room for improvement with respect to the way Internet-connected devices communicate mindlessly. He also cautioned that most users of IoT devices were totally unaware that their activities, movements, behaviours and preferences were being measured, recorded and analysed on an increasingly regular basis.

On the very day that I pen these words news broke that hackers had blocked access to popular websites such as Twitter, Spotify, Netflix and Reddit. They achieved this using the distributed denial of service (DDoS) attack technique, effectively overwhelming the websites by launching visits from tens of millions of separate locations. Critically, the source of these attacks this time was not home computers, but IoT devices such as webcams, smart thermostats, printers, autonomous routers, sensors and CCTV cameras.

The linking factor was that all of these devices were insecure and had been press-ganged into an evil 'botnet' of assault troops without their owners' knowledge. Botnets have been around since at least 2001, traditionally infecting PCs to do their dirty deeds. These days more computers are protected by antivirus software, so botnets now also exploit IoT devices, which most users do not bother to defend.

For some time pundits have warned about the vulnerability of smart homes, asking whether you really want some clown to turn off your central heating in the depth of winter while you're out at work. Or worse, do you want these evil clowns to turn up the wick to boiling point and blow a whole month's worth of your gas bill in a single day? Back then, the target (and victim) was you alone. Now we have the complicity of smart homes in DDoS attacks and degrading the profitability of Spotify and Netflix. What happens if they trace the source of the attacks to the owner of a smart home, alleging lack of due diligence and suing the hapless owner for loss of income? Ignorance is no defence in law.


CON2
R In
(under)
CON1
L In
(under)
Ferrite
Bead
100pF
35904F-Y794
12V DC
CON6
Power
(under)
CON5
M Out
(under)
CON3
L Out
(under)
1nF
100µF
50V
100µF
39µF
400V
39µF
400V
39µF
400V
V1
12AX7
V2
12AX7
470nF
630V
470nF
630V
VR2
100kΩ
ZD3
15V
ZD2
15V
(under) 50kΩ
1µF
1µF
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01101161 RevA
Stereo
Valve
Preamp

Part 1

by Nicholas Vinen

High-performance Stereo Valve Preamplifier

This stand-alone stereo valve preamplifier is based on the *Currawong Amplifier* (November 2015-January 2016) but has a new power supply which runs off a low-voltage DC supply. It has very good performance, especially for a valve preamp, with low distortion and a very high signal-to-noise ratio of 105dB. It's easy to build too, with the preamp and power supply all on one PCB.

ONE OF MY FIRST VALVE preamplifiers was a single-channel (mono) design based on the 12AX7 twin triode. I reused ideas from that design and incorporated them into the *Currawong Amplifier* mentioned above. I've had a number of requests for a stereo preamplifier and when I looked at the original mono design from 12 years ago I realised that I could make significant improvements.

So for a start, this new design is stereo so you don't need to build two separate units (which involved at least three PCBs). It also has a more compact and improved switchmode power supply, which is on the same board as the rest of the components

Futhermare, the earlier design had exposed components on the top of the board which operated at 250V DC, necessitating the application of silicone sealant to render it safe – not a very attractive option. The new design still 'shows off' its components but they are visible through a clear acrylic case, protecting the user from shock risks.

The overall performance is excellent. Take a look at the graphs from an Audio Precision System Two, shown in Figs.1-4. This design has low distortion across the board and no high-frequency rise.

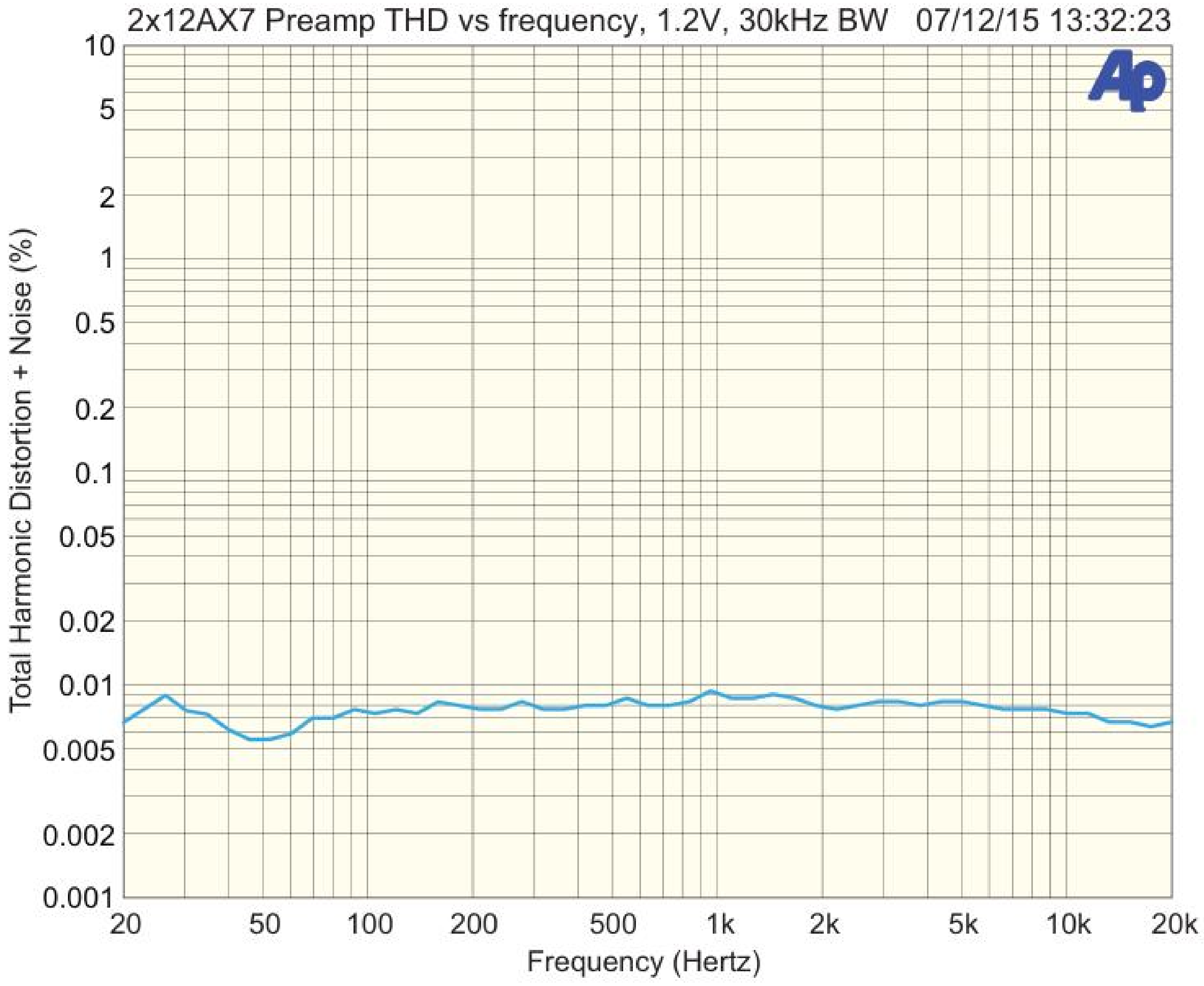


Fig.1: total harmonic distortion plotted against frequency for an input of 300mV RMS and an output of 1.2V RMS (full power for a typical power amplifier). The measurement bandwidth is 30kHz in order to chop out any residual switching artefacts from the power supply while still measuring some of the harmonics of higher audio frequencies. The result is essentially flat with frequency.

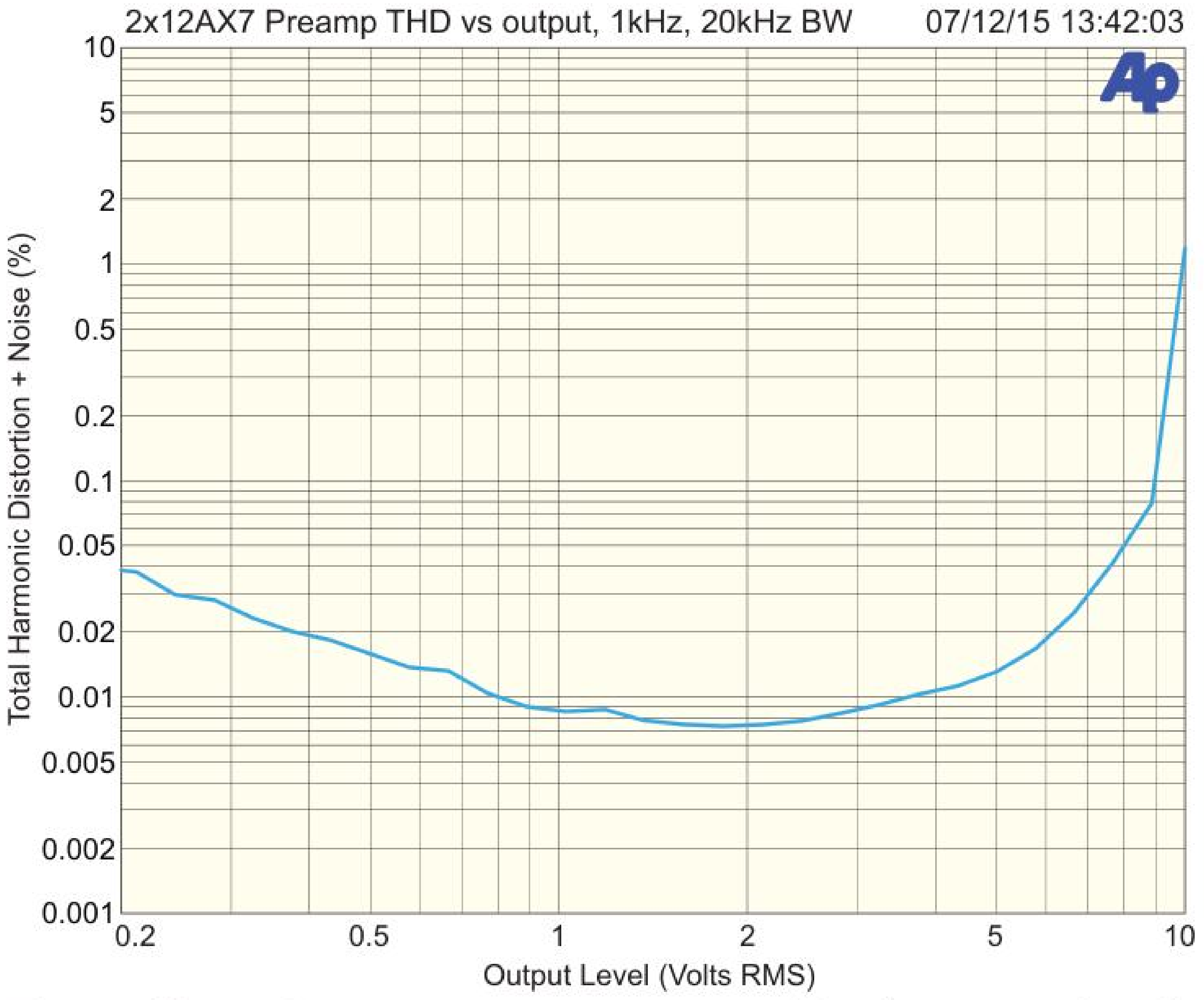


Fig.2: distortion versus output amplitude. For signals below 1V (ie, <250mV RMS input), noise starts to affect the measurement, while for signals above 3V RMS out, the intrinsic second-harmonic distortion of the valve begins to dominate. Distortion rises dramatically for outputs above about 9V RMS as parasitic capacitances interact with the higher slew rate.

The frequency response is pretty flat, with a very slight rise at both 20Hz and 20kHz, due to reduced feedback effectiveness at the extremes.

One of the design points in our circuit is that we've put the volume control pot at the input end rather than the output end. This greatly reduces the chances of overload and gives lower output impedance and lower valve plate loading. In theory, it would increase the noise, but in practice this design has ended up with a better signal-to-noise ratio.

Besides stereo music, another application for a 2-channel valve preamp might be for use as a musical instrument preamplifier, either with two mics on one instrument or two separate instruments. For this application, we have provision for a mixed output with a pot that controls how the two inputs are mixed. This pot, and its associated RCA connector, can be left off for stereo applications.

Since 12AX7 filaments are designed to run from 12.6V, the circuit has been designed to run off 15V DC, with an on-board regulator providing the correct filament voltage. However, we have tested the preamp with a 12V DC supply and it had little effect on performance, so that is a valid option. A 12V automotive supply should be fine as it will normally be above 12.6V most of the time (assuming the battery charge state remains high).

Features and specifications

- Stereo preamplifier with volume control
- Uses two 12AX7 dual triodes (socketed)
- Variable gain: –100dB to +12dB
- Low distortion: <0.01% THD+N @ 20Hz-20kHz, 1.2V output (see Fig.1and 2)
- Flat frequency response: +1,–0dB 20Hz-20kHz (see Fig.3)
- Channel separation: >85dB @ 1kHz, >60dB @ 20kHz (see Fig.4)
- Signal-to-noise ratio: 105dB relative to 1V input (20Hz-20kHz bandwidth)
- Power and HT presence indicator LEDs
- RCA socket inputs and outputs
- Power supply: 13-15V DC @ 650mA
- Power supply reverse polarity protection
- Onboard power switch
- No transformer winding necessary
- Optional mixed output for use with musical instruments.
- Fits in a custom-designed clear laser-cut acrylic case

Circuit description

The full circuit is shown in Fig.5. Both channels are shown, along with the power supply, although the operation of the two channels is identical.

Looking at the left channel only, the signal comes in via RCA socket CON1 and passes through an RF-rejecting low-pass filter comprising a 100Ω resistor with a ferrite bead on one of its leads and a 100pF ceramic capacitor. The signal is then AC-coupled to 50kΩ volume-control potentiometer VR1a via a 470nF MKT capacitor.

The attenuated signal is then AC-coupled to the grid of triode V1a via another 470nF MKT capacitor and a 22kΩ RF stopper. This stopper is quite important. Without it, a fair bit of hash from the power supply can couple into the valve and then be amplified. A 1MΩ bias resistor shunts any grid

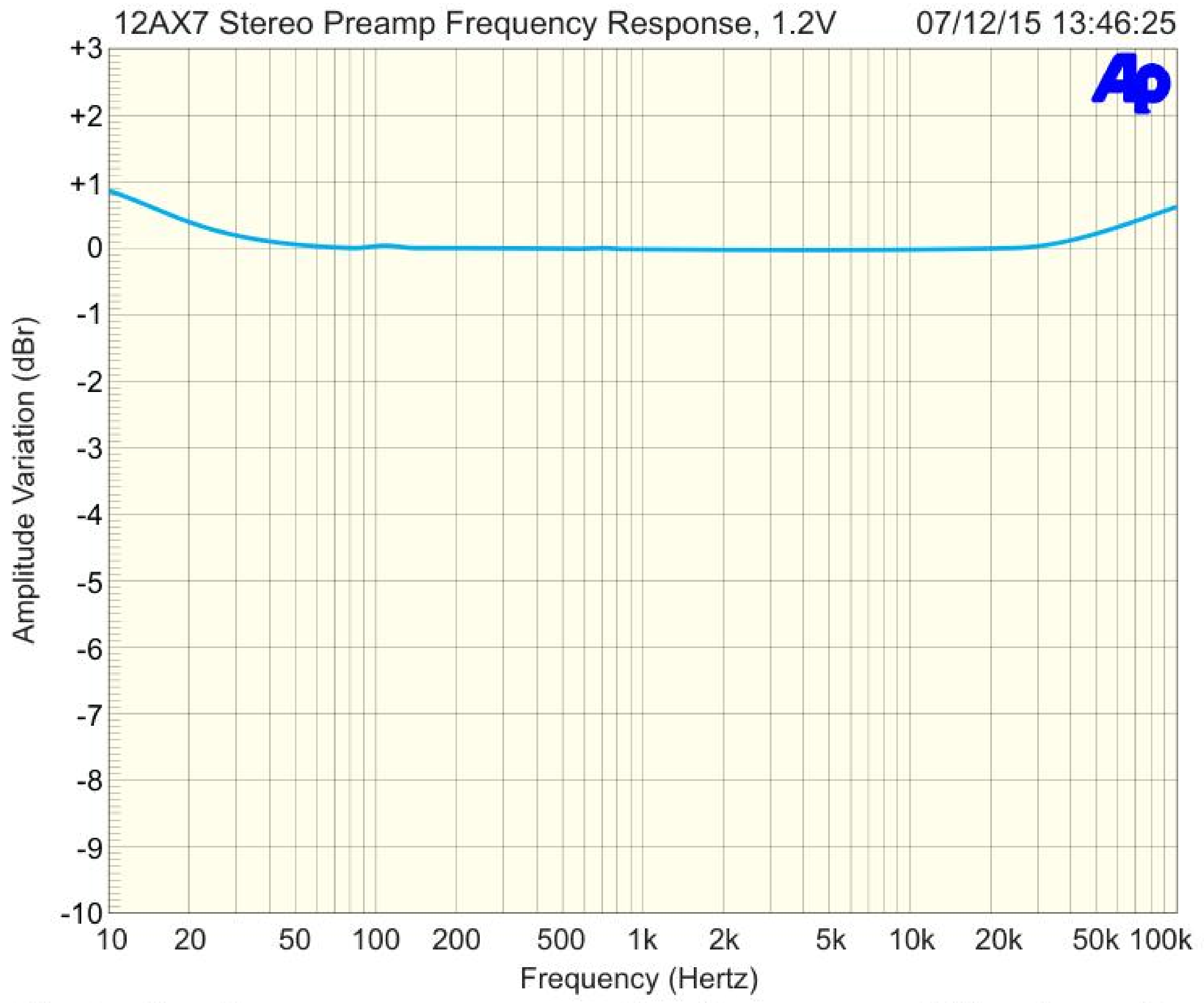


Fig.3: the frequency response for the preamplifier is quite flat, but there is a slight rise in the response below 50Hz due to the increasing impedance of the feedback circuit; feedback starts to drop off, allowing the gain to rise. There is a similar rise above 30kHz, however this is well above the audio band. A small bump is visible at 100Hz due to low levels of mains hum being picked up.

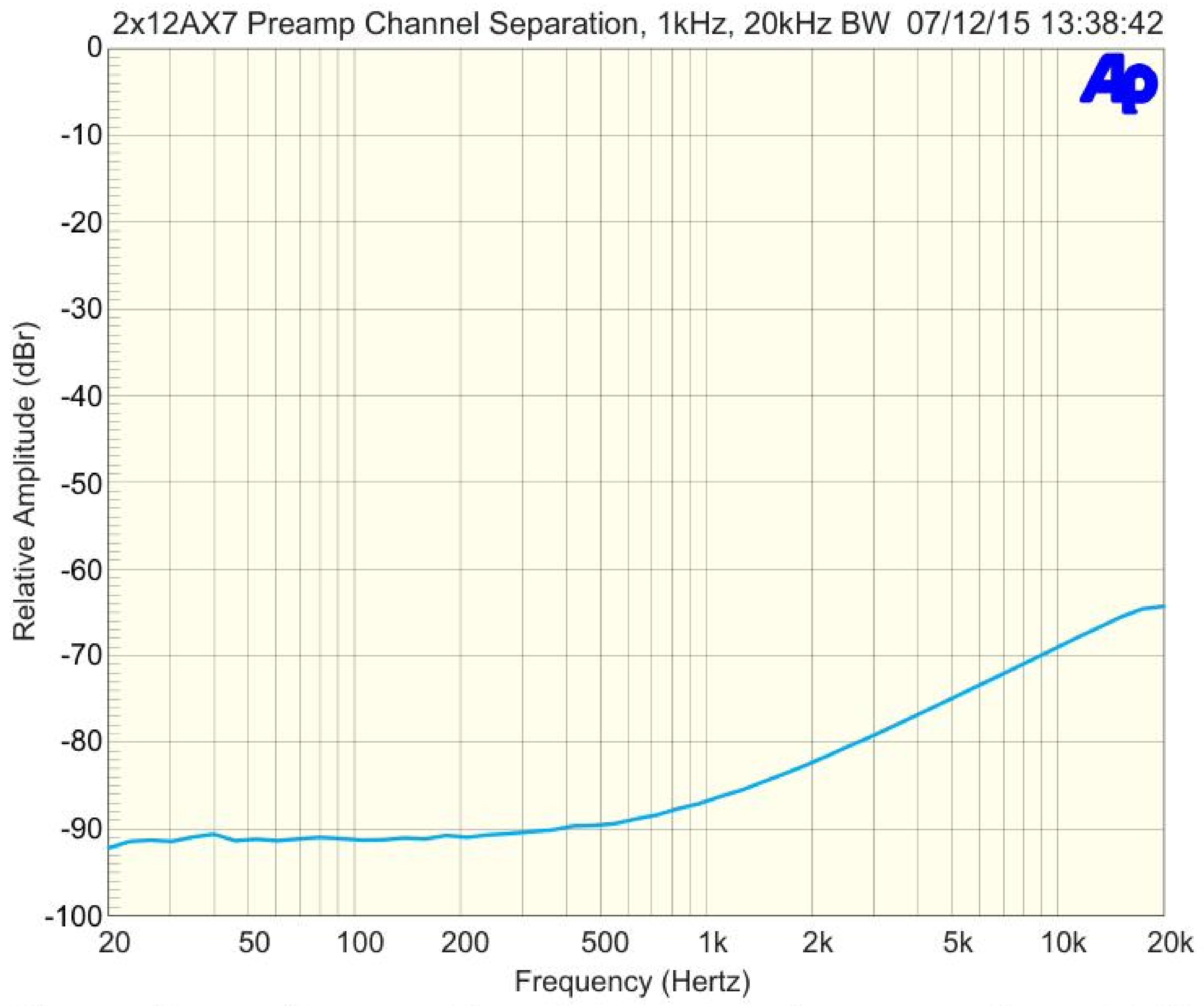


Fig.4: channel separation is very good – more than 90dB below 400Hz, rising to around –65dB at the upper end of the audio band. This was measured with the other channel input terminated with a low impedance. The signal coupled through from one channel to the other at higher frequencies is relatively undistorted so should not result in undesirable intermodulation.

leakage to ground and biases the grid to near-0V.

V1a operates with a current of around 360µA, set by the combination of its 270kΩ anode resistor and 3.3kΩ cathode resistor. The amplified signal at its anode is coupled to the grid of V1b with a 220nF capacitor and the grid is biased with another 1MΩ resistor to ground.

Since V1b needs to handle a higher signal voltage, it runs at around 1.5mA, set by its 68kΩ anode resistor and 680Ω cathode resistor. The output at its anode is coupled to output connector CON3 via another 220nF capacitor, with a 1MΩ resistor setting the DC level to 0V.

AC-coupled negative feedback

The same output signal is also fed back to V1a's cathode via a pair of parallel 470nF capacitors and a 10kΩ resistor. The 10kΩ resistor forms a 4:1 voltage divider with V1a's 3.3kΩ cathode resistor. Say a 100mV positive step is applied to V1a's grid. This will turn V1a on harder, pulling its cathode negative and thus V1b's grid will be pulled negative. That will cut off V1b in turn, causing its anode voltage to rise. Once its anode voltage has risen by 400mV, the 4:1 divider will have caused V1a's cathode to increase by 100mV.

Since it's the grid-cathode voltage which determines how much current a valve conducts, the 100mV increase in V1a's cathode voltage effectively cancels out the 100mV increase in its grid, so it will be back to conducting roughly the same current it was initially. As its anode swing is a tiny fraction of the anode voltage of around 150V, it will reach a steady state. Thus, overall gain of the circuit is accurately set to 12dB by this negative-feedback network.

WARNING! HIGH VOLTAGES

High DC voltages are present in this circuit. In particular, the power supply produces an HT voltage of up to 285V DC and this voltage and other high DC voltages derived from it are present on various parts of the circuit.

Do not touch any part of the circuit when power is applied, otherwise you could get a severe or even fatal electric shock.

The red LED (LED2) in the circuit indicates when high voltages are present. If it is lit, the power supply and various parts on the PCB are potentially dangerous. **To ensure safety, before applying power, the completed preamplifier must be mounted in a suitable case and fitted with a perspex cover, as described in Part 2 next month.**

Mixed and panned outputs

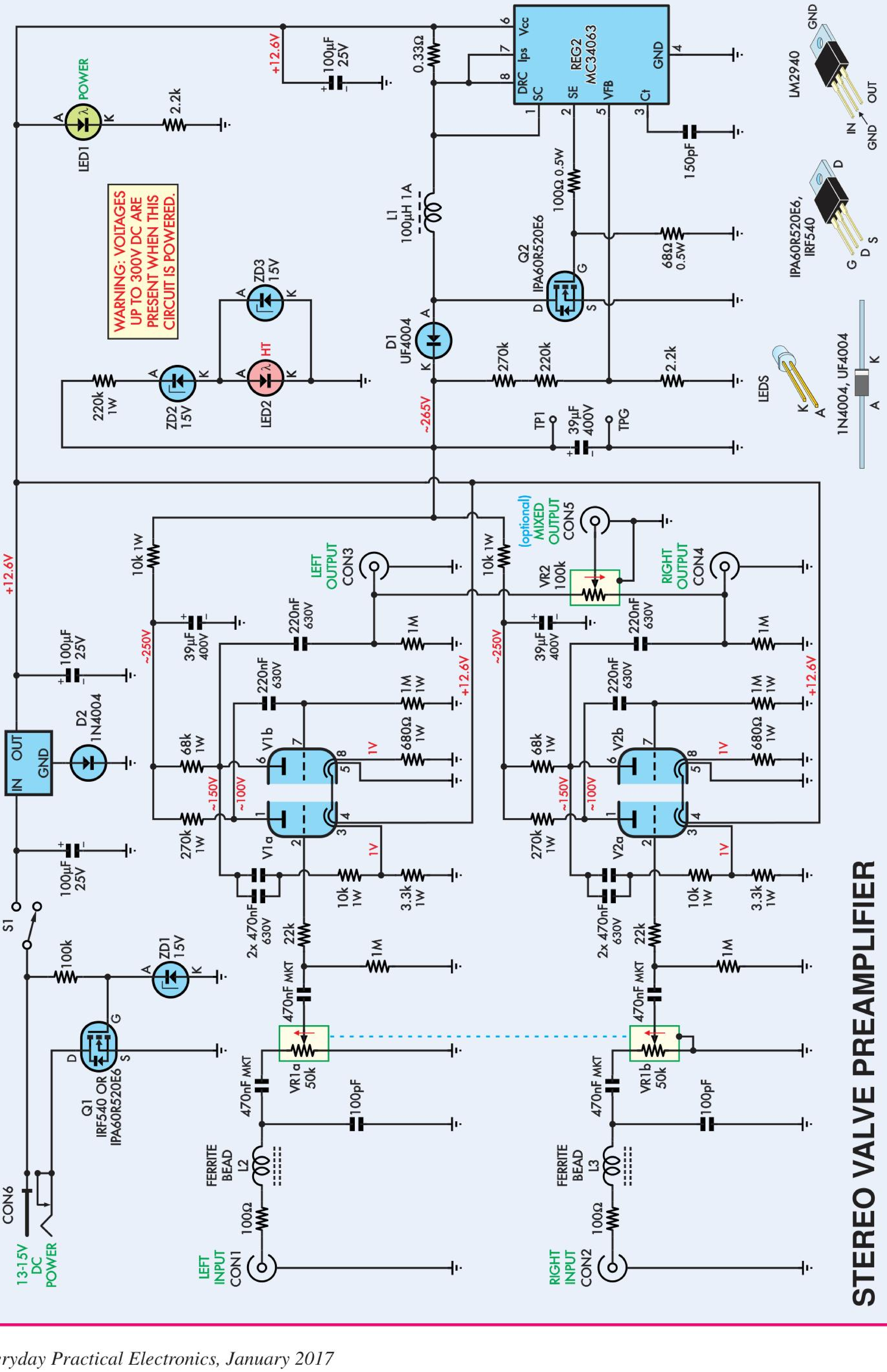
The preamp is intended to be used in stereo applications, with the two channels handling independent signals. However, it could be used as a musical instrument preamplifier. In this case, you can use it as two mono preamplifiers with the two outputs mixed together. For this configuration, VR2 and CON5 are installed and CON3/CON4 can be omitted.

In this case, the output of each channel is mixed by VR2. VR1 still controls the overall output level and with VR2 at mid-setting, an equal amount of each input signal is mixed into the output. As VR2 is rotated clockwise, the output contains more of the amplified signal from CON2 and less of that from CON1; the opposite is true if it's rotated anti-clockwise. Basically, VR2 can be regarded as a pan control, panning from one channel to the other.

Note that if VR2 is fitted, V1b and V2b are loaded with around 50kΩ and the output impedance is increased. Still, as long as the device being fed has a relatively high input impedance, this should not be a problem.

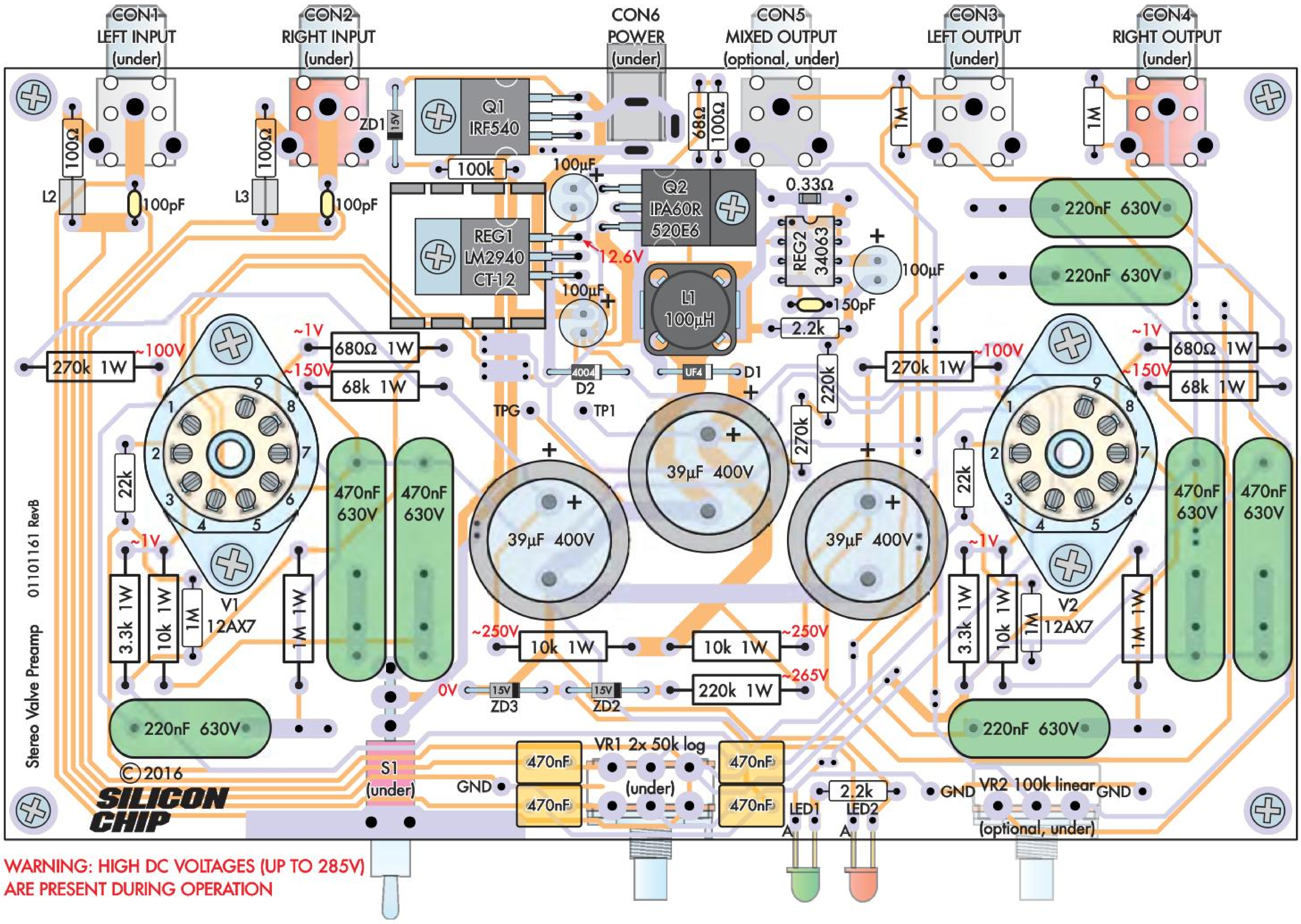
Power supply

A DC input of around 13-15V is required at CON6. As mentioned earlier, supply voltages down to 12V are acceptable; however, the filaments of V1/V2 will run at lower power than they are designed for.


WARNING: VOLTAGES UP TO 300V DC ARE PRESENT WHEN THIS CIRCUIT IS POWERED.
13-15V DC POWER
CON6
Q1 IRF540 OR IPA60R520E6
D G S
100k
ZD1 15V
A K
S1
REG1 LM2940CT-12
IN OUT GND
100µF 25V
D2 1N4004
+12.6V
LED1 POWER
2.2k
220k 1W
ZD2 15V
LED2 HT
ZD3 15V
D1 UF4004
L1 100µH 1A
0.33Ω
100µF 25V
REG2 MC34063
DRC SC Ips Vcc SE VFB Ct GND
1 2 3 4 5 6 7 8
150pF
100Ω 0.5W
68Ω 0.5W
Q2 IPA60R520E6
270k
220k
2.2k
~265V
TP1
TPG
39µF 400V
LEFT INPUT CON1
RIGHT INPUT CON2
100Ω
FERRITE BEAD L2
FERRITE BEAD L3
470nF MKT
100pF
VR1a 50k
VR1b 50k
1M
22k
2x 470nF 630V
10k 1W
3.3k 1W
270k 1W
68k 1W
V1a V1b V2a V2b
~150V
~100V
1V
680Ω 1W
1M 1W
220nF 630V
~250V
10k 1W
LEFT OUTPUT CON3
RIGHT OUTPUT CON4
(optional) MIXED OUTPUT CON5
VR2 100k
LEDS
K A
1N4004, UF4004
IPA60R520E6, IRF540
G D S
LM2940
IN GND OUT

STEREO VALVE PREAMPLIFIER

Fig.5: the complete *Stereo Valve Preamplifier* circuit: each channel uses a 12AX7 dual triode with an overall gain of four (12dB). Amplification is done in two stages, with negative feedback around both to set the gain and also cancel distortion. The circuit runs off a nominal 15V power supply, which is regulated to 12.6V for the filaments, while a ~265V HT rail is produced by switchmode regulator REG2 and high-voltage MOSFET Q2.


CON1
LEFT INPUT
(under)
CON2
RIGHT INPUT
(under)
CON6
POWER
(under)
CON5
MIXED OUTPUT
(optional, under)
CON3
LEFT OUTPUT
(under)
CON4
RIGHT OUTPUT
(under)
100Ω
100Ω
L2
L3
100pF
100pF
ZD1
15V
Q1
IRF540
100k
100µF
+
Q2
IPA60R
520E6
68Ω
100Ω
0.33Ω
REG2
34063
100µF
1M
1M
220nF 630V
220nF 630V
REG1
LM2940
CT-12
12.6V
100µF
+
L1
100µH
150pF
2.2k
~1V
~100V
~150V
680Ω 1W
270k 1W
68k 1W
4004
D2
UF4
D1
220k
TPG
TP1
270k
9
8
7
6
5
4
3
2
1
22k
470nF 630V
470nF 630V
39µF 400V
39µF 400V
39µF 400V
~1V
3.3k 1W
10k 1W
1M
V1
12AX7
1M 1W
V2
12AX7
~250V
10k 1W
10k 1W
~250V
0V
15V
ZD3
15V
ZD2
220k 1W
~265V
220nF 630V
220nF 630V
S1
(under)
470nF
470nF
VR1 2x 50k log
(under)
470nF
470nF
GND
2.2k
LED1
LED2
A
A
GND
VR2 100k linear
GND
(optional, under)
Stereo Valve Preamp
01101161 RevB
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WARNING: HIGH DC VOLTAGES (UP TO 285V) ARE PRESENT DURING OPERATION

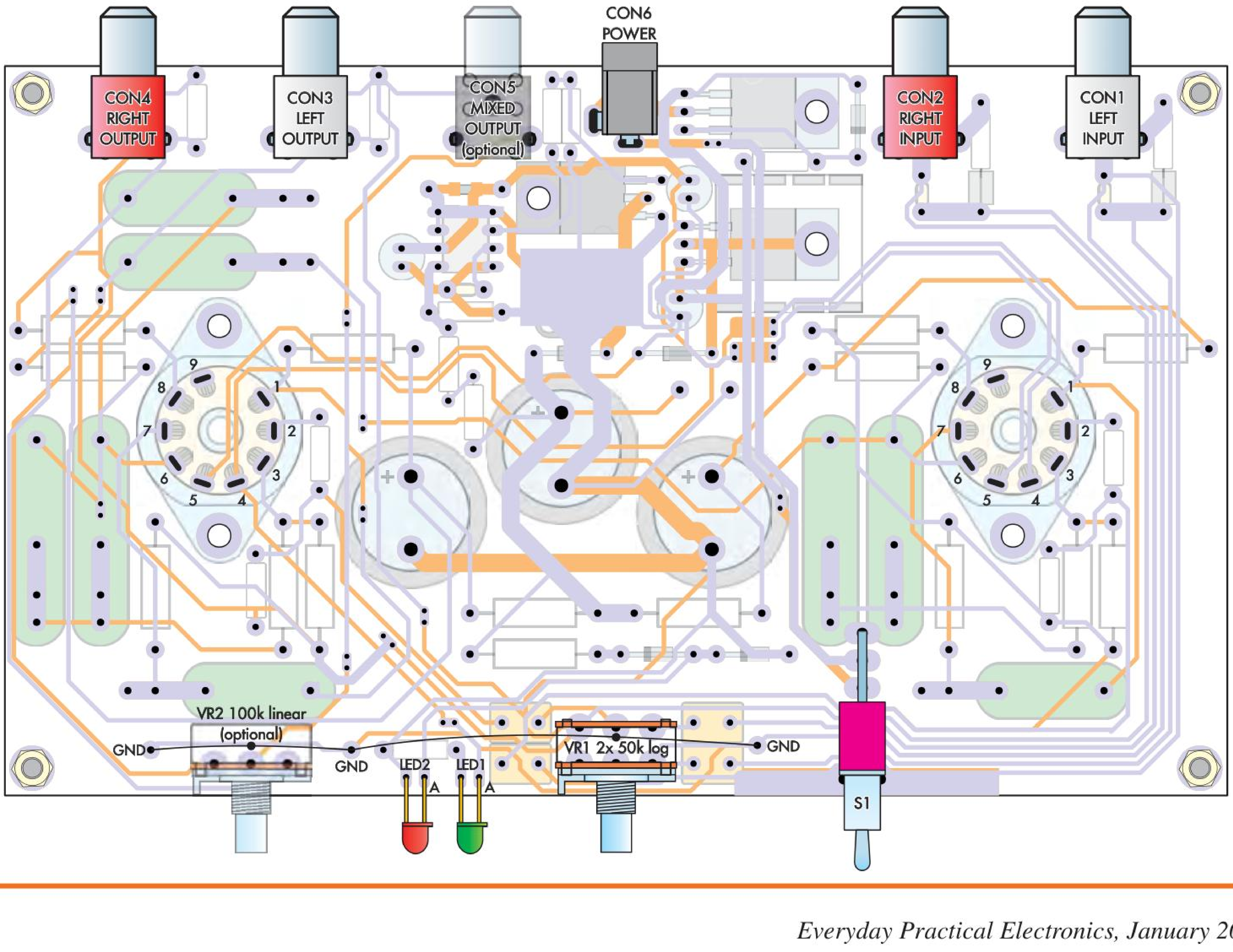

CON6
POWER
CON4
RIGHT
OUTPUT
CON3
LEFT
OUTPUT
CON5
MIXED
OUTPUT
(optional)
CON2
RIGHT
INPUT
CON1
LEFT
INPUT
9
8
1
7
2
6
3
5
4
+
+
+
VR2 100k linear
(optional)
GND
GND
LED2
A
LED1
A
VR1 2x 50k log
GND
S1

Fig.6: top and bottom PCB overlay diagrams. Use these as a guide when assembling the PCB. Start by fitting the components to the top side, which is everything except the connectors, power switch, pots and LEDs. Note the wires used to earth the pot bodies to the nearby GND pads. Leave VR2 and CON5 out if building a stereo preamplifier. CON3 and CON4 are optional if VR2 and CON5 are fitted.

MOSFET Q1 provides reverse polarity protection, with much lower voltage loss than a simple diode, even a Schottky type. If the supply polarity is correct, Q1's gate is pulled positive with respect to its source and so ground current can flow back to CON6 normally. However, if the supply polarity is reversed, Q1's gate is pulled negative and thus its channel will not conduct. Its body diode is also reverse biased in this condition, so the only current that will flow is a few microamps through ZD1 and its series 100kΩ resistor.

ZD1 protects Q1 in case the supply voltage spikes above 20V for more than a very brief period.

Power switch S1 interrupts the supply to REG1, a low-dropout automotive 12V regulator. Its ground pin is 'jacked up' by around 0.6V by diode D2, increasing its output to around 12.6V to suit the filament requirements of the 12AX7 valves. 100µF input bypass and output filter capacitors are provided and these should ideally be low-ESR types for supply stability.

LED1 indicates the presence of the 12.6V rail. As well as running the filaments directly, this rail also supplies switchmode regulator REG2, which is configured as a boost regulator to produce the HT supply.

When REG2's internal transistor is switched on, current flows through the 0.33Ω shunt, into pin 1 (switch collector), out of pin 2 (switch emitter) and through a voltage divider formed by 100Ω and 68Ω resistors. The voltage produced by this divider drives the gate of high-voltage logic-level MOSFET Q2.

So when REG2's internal switch is on, Q2 is biased into conduction and it pulls current through the 0.33Ω shunt and inductor L1 to ground. This charges up L1's magnetic field. REG2 has an internal oscillator that we've set to around 100kHz using a 150pF capacitor from pin 3 (Ct) to ground. L1 continues to charge either until the ~7.5µs period set by this oscillator expires or the current builds to around 1A, at which point the voltage across the 0.33Ω shunt exceeds the ~300mV current trip level, as sensed by pin 7 (Ips).

In either case, REG2's internal transistor is switched off and the 68Ω resistor quickly pulls Q2's gate to 0V, switching it off. This causes the magnetic field in L1 to begin collapsing, which continues to 'push' current through the inductor in the same direction as it was flowing before it was interrupted.

Since the 'input' side of L1 is still connected to the 12.6V supply, the only way for current to continue to flow is for high-voltage ultrafast diode D1 to become forward biased. As a result, the voltage at D1's anode increases dramatically. Before L1's magnetic field can collapse completely, the oscillator in REG2 causes its internal transistor to switch back on, recharging it and repeating the cycle.

When the circuit is first powered up, the voltage at D1's cathode will start at around 12V, but as the three 39µF 400V capacitors charge up, this voltage will continue to rise until it reaches nearly 300V.

One of two things then happens. The voltage is either limited by the fact that the current limit enforced by REG2 prevents any more energy flowing into L1 in each cycle than is consumed by V1 and V2, or the voltage rises high enough that the voltage at the voltage feedback pin of REG2 (pin 5) rises above 1.25V. If this happens, REG2 will skip pulses until the output voltage drops, then it will switch back on to regulate said voltage to the set level.

However, we have designed this circuit so that it can't quite produce a high enough output voltage to regulate properly. This is because the pulse skipping that's used to regulate the output voltage causes sub-harmonics of the 100kHz switching frequency to be radiated and depending on how many pulses are skipped, these could be in the audio band (ie, below 20kHz) and could couple into the preamplifier, reducing its signal-to-noise ratio.

This means that the HT voltage is not actually regulated, but that isn't much of an issue as the 12AX7s will run happily off quite a wide range of voltages; anywhere in the range of 250-300V will do. The feedback divider really only exists to prevent damage in case one or both valves are removed, fail or becomes disconnected during operation. In this case, it will limit the HT rail to around 285V DC.

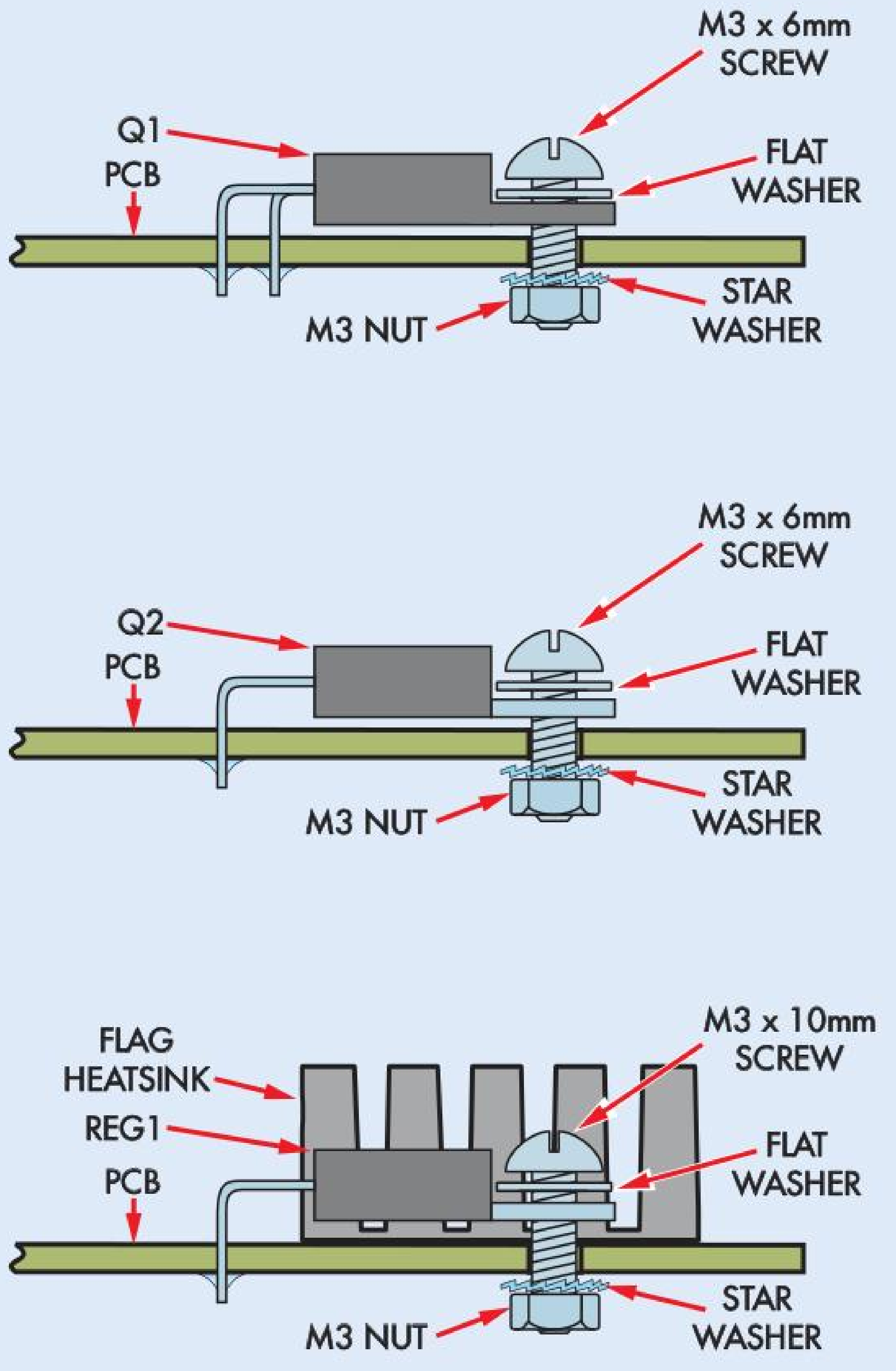


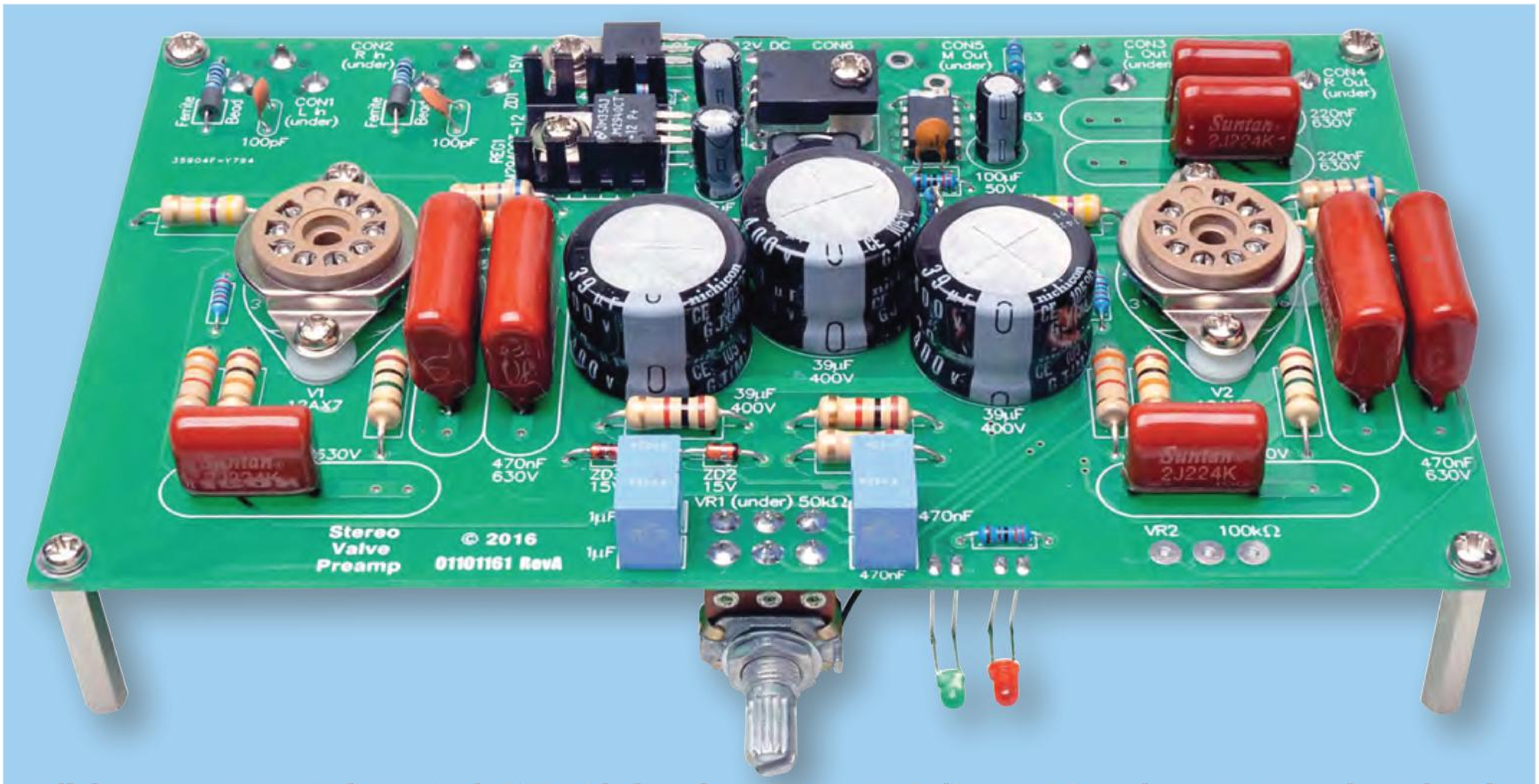
Fig.7: mounting details for Q1 (top), Q2 (middle) and REG1 (bottom). Note that a longer machine screw is used for REG1 and that Q1 is in a fully insulated package with its centre lead bent over and soldered closer to the body than the other two.

The actual operating HT voltage will depend on a few factors, but mainly on the exact value of L1, the 0.33Ω shunt, REG2's current-limit voltage sense threshold and the 150pF capacitor. These all affect how much energy L1 can store for each cycle, or in the case of the 150pF capacitor value, the maximum number of charge cycles per second.

We've set the circuit up so that in most cases, the actual HT voltage produced should be high enough for correct operation, but not so high that pulse skipping is employed (ie, below the ~285V regulation target). In our prototype, it reaches 280V after about 30 seconds and eventually drops to about 265V once the valves have fully warmed up.

Construction

All parts are carried on the main PCB and assembly is quite straightforward. It should only take a couple of hours for



All the parts are mounted on a single PCB with the volume pot, power indicator LEDs and connectors on the underside. The board caters for various sizes of 630V capacitors.

experienced constructors. The board itself is available from the *EPE PCB Service*, coded 01101161 and measures 170 × 102mm. Referring to the PCB top-side overlay diagram Fig.6, begin by fitting the smaller resistors.

It's best to check all the resistor values with a DMM before fitting them. Don't forget that the 68Ω and 100Ω resistors must be 0.5W types and that two of the other 100Ω resistors have ferrite beads slipped over their leads before they are soldered in place. The 0.33Ω resistor should also be fitted now, whether it's a through-hole or SMD type.

Follow with diodes D1 and D2 and zener diodes ZD1-ZD3. Don't get the three different types mixed up and pay careful attention to polarity. This is indicated by the cathode stripes shown on Fig.6 and the PCB silkscreen.

Having done that, solder inductor L1 in place. This is most easily done by first applying a little flux paste to the pads, then adding some solder to one of the pads – the right end if you are right-handed or left if you are left-handed. Then place the inductor next to its final position, heat the solder on that pad and slide the component into place.

You will find that once it contacts the solder, it will take a few seconds to heat the component up to the point where it will adhere and you can then move it into its final location. It's then just a matter of adding solder to the opposite pad and continuing to heat it until it adheres to both the pad and component lead. Finally, go back to the other side, add some fresh solder and heat it further, again making sure it forms a good fillet.

Next, solder REG2 to the board. Don't use a socket and make sure its pin 1 dot is at upper-left, as shown on Fig.6. Press it down flat on the PCB before soldering the pins. Follow with the larger (1W) resistors, using a similar procedure as before.

Now bend the leads of Q1 and Q2 down through 90° about 5mm from the body of each component and attach them to the board using M3 × 6mm machine screws and nuts, with a shakeproof washer under each nut and a flat washer under the head. Don't get these two components mixed up – Q2 should be encapsulated in black plastic, while Q1 may have a metal tab (if you are using an IRF540) – see Fig.7 for details.

Once the screws are done up tightly and the parts checked for proper alignment, solder and trim the leads.

Having done that, solder the ceramic and MKT capacitors in place. These can all go in either way around, as they are non-polarised. Refer to Fig.6 to see which value goes where.

Now fit regulator REG1. The procedure is the same as for Q1 and Q2 except that a flag heatsink is positioned under the regulator's tab and an M3 × 10mm machine screw is used to secure it instead of an M3 × 6mm screw. Make sure that the regulator's body and heatsink are square and that the screw is done up tightly before soldering the leads – see Fig.7.

Fitting the valve sockets

The valve sockets are retained mechanically, to avoid placing stress on the solder joints when inserting and removing the valves. Each is held in place with two M3 × 10mm machine screws, with a nylon nut and two nylon washers used to form a spacer. Fit a shakeproof washer under the nuts.

Basically, it's just a matter of inserting an M3 × 10mm machine screw through the top of the two mounting holes on the valve socket and screwing a nylon nut onto each thread. Do the nuts up tight, then slip pairs of nylon washers over each screw shaft and feed these through the mounting holes on the PCB. You'll need to coax the nine solder tabs into the slots on the PCB, then the whole thing should drop into place.

Use the shakeproof washers and nuts to fasten it in place, make sure the nuts are done up tightly, then solder and trim the nine tabs on each socket.

You can now solder the three small and three large electrolytic capacitors in place (see Fig.6). In each case, make sure that the longer lead goes through the hole nearest the '+' symbol.

Underside components

Now it's time to fit the components on the other side of the board – see Fig.6. The RCA connectors fitted are CON1-CON4 (for a stereo preamplifier) or CON1, CON2 and CON5 (mixed mono preamplifier for instruments). CON1 and CON3 are white, CON2 and CON4 are red and CON5 can be black.

Unfortunately, white RCA sockets aren't that easy to come by. A set of four is available from the Silicon Chip Online Shop, including red, white, black and yellow. These have a slightly different footprint to the types available from Jaycar and Altronics, but as you can see from our prototype, the leads can be bent so that they fit. In fact, they are a little easier to fit than the other type and as a bonus, have a consistent mounting height, unlike some types which can vary between different colours.

Whichever sockets you are fitting, make sure they are pressed down fully onto the PCB and are perpendicular to the board edge before soldering the three pins. You can also fit DC socket CON6 now, on the same side of the board, again making sure it's nice and square before soldering.

Before fitting the pot(s), you will need to use a file to scrape off a small area of the passivation on top of the body so that you can solder an earth wire in place. Basically, it's just a matter of holding the body in a vice using a couple of scrap pieces of timber to prevent damage and then a few passes with a file should reveal a shiny surface. **Don't breathe in the dust produced; it may be toxic.**

If your pot(s) have long shafts, you will also want to cut them short now. Use a hacksaw and file to cut it/them to no more than 15mm. Then, referring to Fig.6, solder the pot or pots in place on the underside of the board. Solder some tinned copper wire between the provided GND pads, across the top of the pot body(s), then solder the wire to the pot(s) to 'earth' them.

Now fit power switch S1 in place, making sure it's first pushed down fully onto the PCB. Finally, install LED1 and LED2. Check Fig.6 to determine the required orientation, then bend the LED leads through 90°, 6mm from the base of the lenses. Solder the LEDs in place on the underside of the board, with the horizontal portion of the leads 13mm from the bottom of PCB. This may be easier to do if you cut a 13mm cardboard spacer first.

Parts list

1 double-sided PCB available from the *EPE PCB Service*, coded 01101161, 170 × 102mm
1 set of clear acrylic laser-cut case pieces*
1 acrylic adhesive (see Part 2)
4 rubber feet
1 15V 1A plugpack
2 12AX7 dual triode valves
2 9-pin valve sockets
1 100µH 12 × 12mm SMD inductor* (L1) (Murata 48101SC; element14 2112367)
1 50kΩ 16mm dual log pot (VR1)
1 100kΩ 16mm linear pot (VR2; optional, see text)
2 knobs, to suit VR1 and VR2
1 mini TO-220 flag heatsink, 6073B type
2 ferrite beads (L2,L3)
2 white switched RCA sockets (CON1,CON3)*
2 red switched RCA sockets (CON2,CON4)*
1 black switched RCA socket (CON5; optional, see text)*
1 PCB-mount DC socket to suit plugpack (CON6)
1 PCB-mount right-angle mini SPDT toggle switch (S1) (Altronics S1320)
2 M3 × 6mm machine screws
5 M3 × 10mm machine screws
4 M3 × 32mm machine screws
7 M3 shakeproof washers
3 flat washers, 3mm I.D.
7 M3 nuts
4 M3 nylon nuts
8 nylon washers, 3mm I.D.
4 M3 × 12mm nylon machine screws
4 6.3mm M3 tapped nylon spacers
4 12mm M3 tapped nylon spacers
4 25mm M3 tapped metal spacers
1 200mm length 0.7mm diameter tinned copper wire

Semiconductors
1 LM2940CT-12 12V 1A low-dropout regulator (REG1)
1 MC34063 switchmode regulator (REG2)
1 IRF540 or IPA60R520E6* N-channel MOSFET (Q1)
1 IPA60R520E6* 600V N-channel MOSFET or equivalent (Q2)
1 green 3mm LED (LED1)
1 red 3mm LED (LED2)
3 15V 1W zener diodes (ZD1-ZD3)
1 UF4004 ultrafast diode or equivalent (D1)
1 1N4004 1A diode (D2)

Capacitors
3 100µF 25V low-ESR electrolytic
3 39µF 400V low-profile snap-in electrolytic (Nichicon LGJ2G390MELZ15* (Mouser)
4 470nF 63V MKT
4 470nF 630V metallised polyester
4 220nF 630V metallised polyester
1 150pF disc ceramic
2 100pF C0G/NP0 disc ceramic

Resistors (1W, 5%)
2 1MΩ
2 270kΩ
1 220kΩ
2 68kΩ
2 10kΩ
2 3.3kΩ
2 680Ω

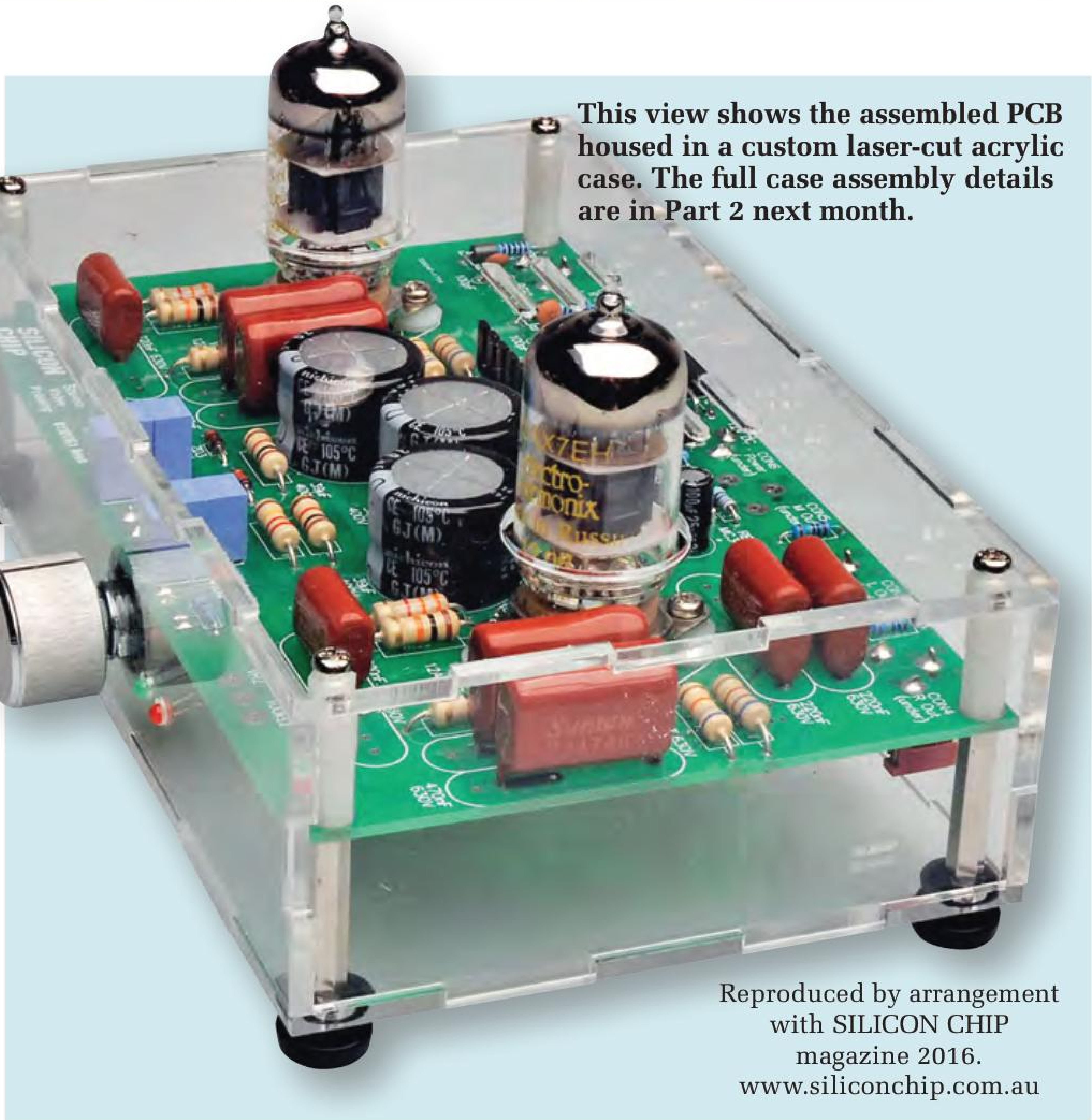
Resistors (0.25W, 1%)
4 1MΩ
1 270kΩ
1 220kΩ
1 100kΩ
2 22kΩ
2 2.2kΩ
1 100Ω 0.5W
2 100Ω
1 68Ω 0.5W
1 0.33Ω through-hole or SMD 1206 resistor*

* From Silicon Chip Online Shop; **www.siliconchip.com.au/shop**

Testing

The first step is to check that the HT power supply is working but before doing this, temporarily attach the four tapped spacers in each corner using an M3 machine screw.

Test points are provided to monitor the HT voltage, near the centre of the PCB, however it's easier and safer to use DMM alligator clip leads to connect to the anode of ZD3 (negative lead) and the right-hand end of the 220kΩ 1W resistor (positive lead) – see the 0V and ~265V markings on Fig.6. Set your DMM to a range which will read 300V DC and plug the power supply into the PCB but not the mains.



This view shows the assembled PCB housed in a custom laser-cut acrylic case. The full case assembly details are in Part 2 next month.

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Make sure nothing conductive is near the PCB and it isn't close to the edge of your bench. Then, keeping clear of the assembly, plug the power supply into mains. Within about one second of power being applied, the HT voltage should reach 285V or thereabouts and stabilise, with the green and red LEDs lit. Either way, switch off power and wait for it to discharge to a safe level (below 40V) before continuing.

If there's a fault, once the HT rail has discharged, check component placement/orientation and solder joints.

Assuming all is well, connect regular probes to your DMM but leave it on the 300V (or higher) range. Power the board back up and measure the voltage between pins 4 and 5 on both valve sockets (see Fig.6). You should get a reading close to 12.6V. Now check the voltages at the other pins relative to GND. You should get ~285V for pins 1 and 6 and close to 0V for pins 2, 3, 7 and 8. Pin 9 is not connected to anything.

You can now switch the power off and push the two valves into their sockets. They will be stiff, especially if this is the first time the sockets have been used. You may find it easier to gently rock them in. In theory, you can install valves with HT voltage present, but it's much safer to wait for it to decay first.

With the valves in place, power back up and check the HT voltage, using the test pads in the centre of the board. It should rise to around 270V at first and then slowly decay to around 250-260V as the valves warm up and their operating current builds.

In the unlikely event that the HT supply remains above 280V and there are no board or valve faults, this may be because component variations are causing the supply to deliver more current than it's designed to. The simple solution is to reduce the value of the 150pF capacitor to 120pF. This will increase the switchmode frequency and reduce the duty cycle and should bring the HT back in line.

If you need to do this, don't forget to wait for LED2 to go out before working on the board.

Finally, perform a live signal test. Switch off, wait for LED2 to go out and connect a signal source to CON1/CON2 and an amplifier to CON3/CON4. Next, turn the volume right down, power on and wait 30 seconds or so for voltages to stabilise. Then press play on the signal source and slowly advance the volume until you hear clean, undistorted sound.

If the sound is distorted or missing, switch off and carefully check the component values around each valve socket as well as the solder joints.

Putting it in the case

That's all for this month. In the second and final article next month, we'll go over the details of how to put together the custom laser-cut case and fit the PCB inside it.

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Win a Microchip TimeFlash Oscillator Programming Kit with 2 Socket Cards

EVERYDAY PRACTICAL ELECTRONICS is offering its readers the chance to win a Microchip TimeFlash Oscillator Programming Kit with 2 Socket Cards (DSC-TIMEFLASH-KIT2)!

The TimeFlash programmer allows users to rapidly program Microchip's field-programmable MEMS oscillator to a custom frequency in seconds, minimising design time by enabling fast prototyping and testing. Microchip's MEMS oscillators are available in industry-standard packages that are drop-in replacements to standard crystal oscillators.

Includes socket cards in two different sizes: 3.2 × 2.5 mm and 2.5 × 2.0 mm. Some of the features include: custom frequencies in seconds with immediate design verification; support for all Microchip MEMS oscillator package sizes; support for CMOS, LVPECL, LVDS, and HCSL output types; and easy to use interface with auto software update.

The TimeFlash Kit supports Microchip's new DSC6000 family of MEMS oscillators which are the industry's smallest MEMS MHz oscillators with the lowest power consumption over the full frequency range of 2kHz to 100MHz.

The single-output DSC6000 MEMS oscillators are excellent choices for use as clock references in small, battery-powered devices such as wearables and Internet of Things (IoT) devices in which small size, low power consumption, and long-term reliability are paramount. The TimeFlash field programming kit provides instant frequency generation by fusing the One-Time Programmable (OTP) memory in a blank DSC6000.

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September 2016 ISSUE WINNER

Dr Stuart Radley, who works at Knockbank, Laurencekirk, UK

He won a Microchip 8-bit Wireless Development Kit, valued at £226.00

High Visibility 6-Digit LED GPS Clock

Want a really bright 6-digit clock that you can see at a considerable distance? Would you like it to have GPS time precision with automatic time zone and daylight saving adjustment? Well, have we got a clock for you! This new clock design uses six 56mm-high LED digits which are so bright that they seem larger than they really are. And with optional GPS time-keeping, it would be ideal for travellers, as well those who simply want a highly visible clock.

Following the *6-Digit Nixie Clock* in the February and March 2016 issues, we have had a number of enquiries from readers who want a modern clock (not Nixies!) with GPS accuracy but also high visibility. So, we have combined the GPS time-keeping features with a 6-digit LED display which comes in a range of colours: red, blue, yellow, green and emerald green. For sheer impact, we suggest that you go for the blue or the emerald green.

The unit can be wall-mounted or can sit on a desk. It runs from a 12-18V DC plugpack or power supply and has solid or flashing colons (at 1Hz).

With a GPS module, as long as the unit is placed where it can receive the satellite transmissions, all you have to do is power it up and it will show the correct time year-round – even after an extended blackout.

The unit is housed in a custom laser-cut 3mm clear or tinted acrylic case. The case incorporates two slots for screw heads to hold it on the wall as well as cut-outs for the pushbuttons and DC socket and holes for the piezo buzzer sound to exit the case.

An infrared remote control can be used to change the display brightness, show the date, set the time and alarm and also to use the unit as a timer. It can count up or down, showing fractional seconds for times under one hour and sound its piezo buzzer after a preset period. The same piezo buzzer is used for its 7-day alarm feature – a different alarm time can be set for each day and the alarm can be enabled or disabled for any given day.

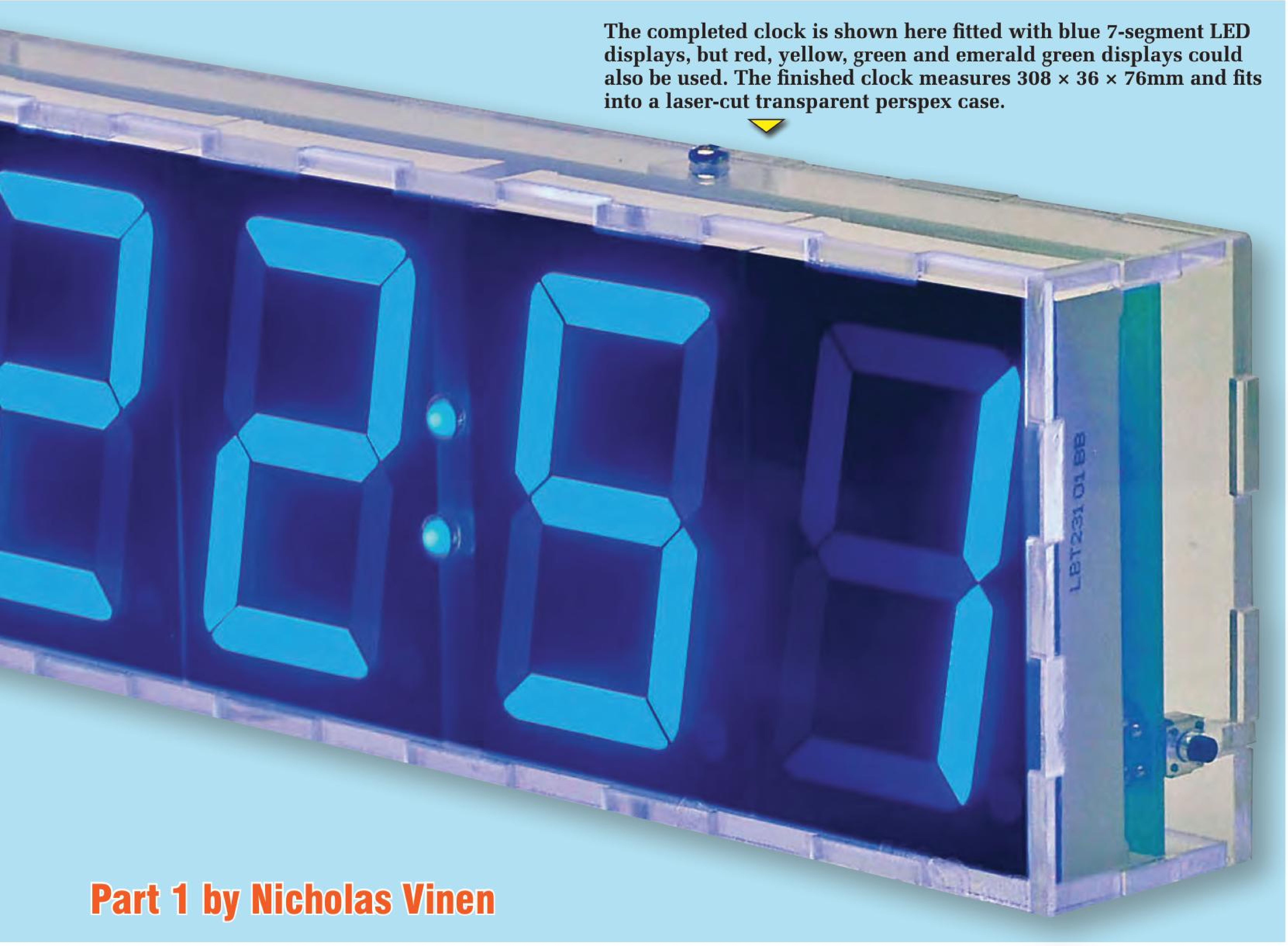
The display can be set to 12 or 24-hour time, with or without leading zero blanking. Time is kept using an internal crystal which can be trimmed for long-term accuracy (not necessary if a GPS module is fitted). An on-board light sensor allows the display to automatically dim at night. Basic functions, such as setting the time or showing the date can be performed using two on-board pushbuttons. All functions can also be performed using the infrared remote control.

All parts mount on a single PCB for easy construction and it's controlled by a PIC32 microcontroller with 512KB of flash memory. Most of this is taken up with geographic data which is used to determine the local time zone and daylight savings rules, based on the GPS coordinates.

Most GPS modules are suitable and start at around a fiver – we mention some possibilities later in the article.

Circuit description

The complete circuit of the GPS-disciplined LED clock is shown in Fig.1. The digit anodes are driven by MPSA13 monolithic NPN Darlington transistors Q20-Q25, which are configured as emitter-followers (ie, current buffers) which are in turn driven by the outputs of a single HEF4028 CMOS



The completed clock is shown here fitted with blue 7-segment LED displays, but red, yellow, green and emerald green displays could also be used. The finished clock measures 308 × 36 × 76mm and fits into a laser-cut transparent perspex case.

Part 1 by Nicholas Vinen

decimal decoder, IC2. The Darlingtons are required due to the very weak drive capabilities of IC2 (~1mA). IC2 drives one of its B0-B9 outputs high and the others low, depending on the states of the S0-S3 inputs. For 'invalid' input combinations, all outputs are low.

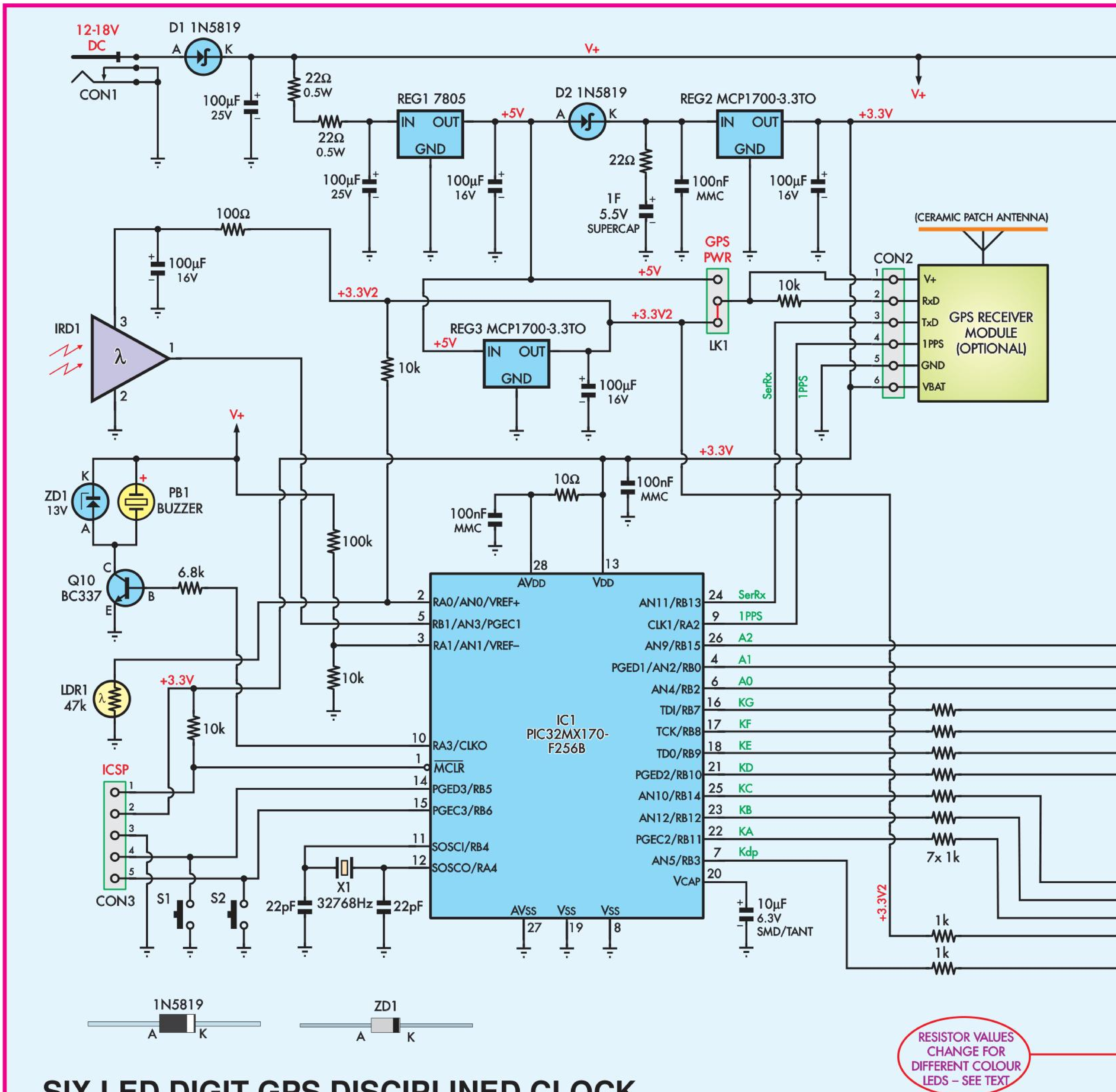
An HEF4028 is used rather than a regular 4028B due to its higher maximum voltage rating (18V vs 15V), giving more flexibility in matching the DC supply voltage to the LED display requirements.

IC2's inputs are controlled by level shifter IC3, a 40109 which is also a CMOS device. The VDD pins of IC2 and IC3 connect to the main DC supply of around 15V, while IC3's VCC pin connects to the 3.3V supply, which is also used by the microcontroller. Thus, the micro's 3.3V outputs are suitable for driving IC3's A, B and C inputs, which are then level-shifted to 0-15V signals at pin 4 (OA), pin 5 (OB) and pin 11 (OC) to control IC2.

Features and specifications

- Choice of six display colours: blue, emerald green, red, green, yellow, white
- Optional GPS module for automatic time zone and daylight saving
- Housed in custom laser-cut wall-mounting transparent acrylic case
- Adjustable brightness
- Automatic dimming based on ambient light
- Date display (via pushbutton/remote control)
- Manual time zone override with GPS module
- Keeps time for over one hour during blackout
- Power consumption: depending on display colour, ~100-500mA @ 12-18V
- Some colour versions suitable for use with 12V automotive supply
- Also operates as count-up/count-down timer with sub-second resolution
- 7-day alarm with piezo buzzer
- Functions can be controlled with universal infrared remote

IC3's enable pins are all tied high to VCC, so these outputs are always active. If the micro wants to disable drive to the digits, it simply sets IC3's inputs A, B and C high, which causes output O7 (pin 4) of IC2 to be selected. B7 is not connected to anything, so all the Darlington transistors are switched


12-18V DC
CON1
D1 1N5819
A
K
V+
100µF 25V
22Ω 0.5W
22Ω 0.5W
REG1 7805
IN OUT GND
+5V
D2 1N5819
22Ω
1F 5.5V SUPERCAP
100nF MMC
REG2 MCP1700-3.3TO
+3.3V
100µF 25V
100µF 16V
100µF 16V
100Ω
100µF 16V
+3.3V2
GPS PWR
LK1
10k
(CERAMIC PATCH ANTENNA)
CON2
V+
RxD
TxD
1PPS
GND
VBAT
GPS RECEIVER MODULE (OPTIONAL)
IRD1
REG3 MCP1700-3.3TO
100µF 16V
SerRx
1PPS
ZD1 13V
PB1 BUZZER
Q10 BC337
6.8k
100k
10k
10Ω
100nF MMC
100nF MMC
AVDD
VDD
28
13
RA0/AN0/VREF+
RB1/AN3/PGEC1
RA1/AN1/VREF–
RA3/CLKO
MCLR
PGED3/RB5
PGEC3/RB6
SOSCI/RB4
SOSCO/RA4
IC1 PIC32MX170-F256B
AN11/RB13
CLK1/RA2
AN9/RB15
PGED1/AN2/RB0
AN4/RB2
TDI/RB7
TCK/RB8
TD0/RB9
PGED2/RB10
AN10/RB14
AN12/RB12
PGEC2/RB11
AN5/RB3
VCAP
SerRx
1PPS
A2
A1
A0
KG
KF
KE
KD
KC
KB
KA
Kdp
7x 1k
1k
1k
+3.3V2
10µF 6.3V SMD/TANT
LDR1 47k
ICSP
CON3
S1
S2
22pF
X1 32768Hz
22pF
AVSS
VSS
VSS
27
19
8
1N5819
ZD1
RESISTOR VALUES CHANGE FOR DIFFERENT COLOUR LEDS – SEE TEXT

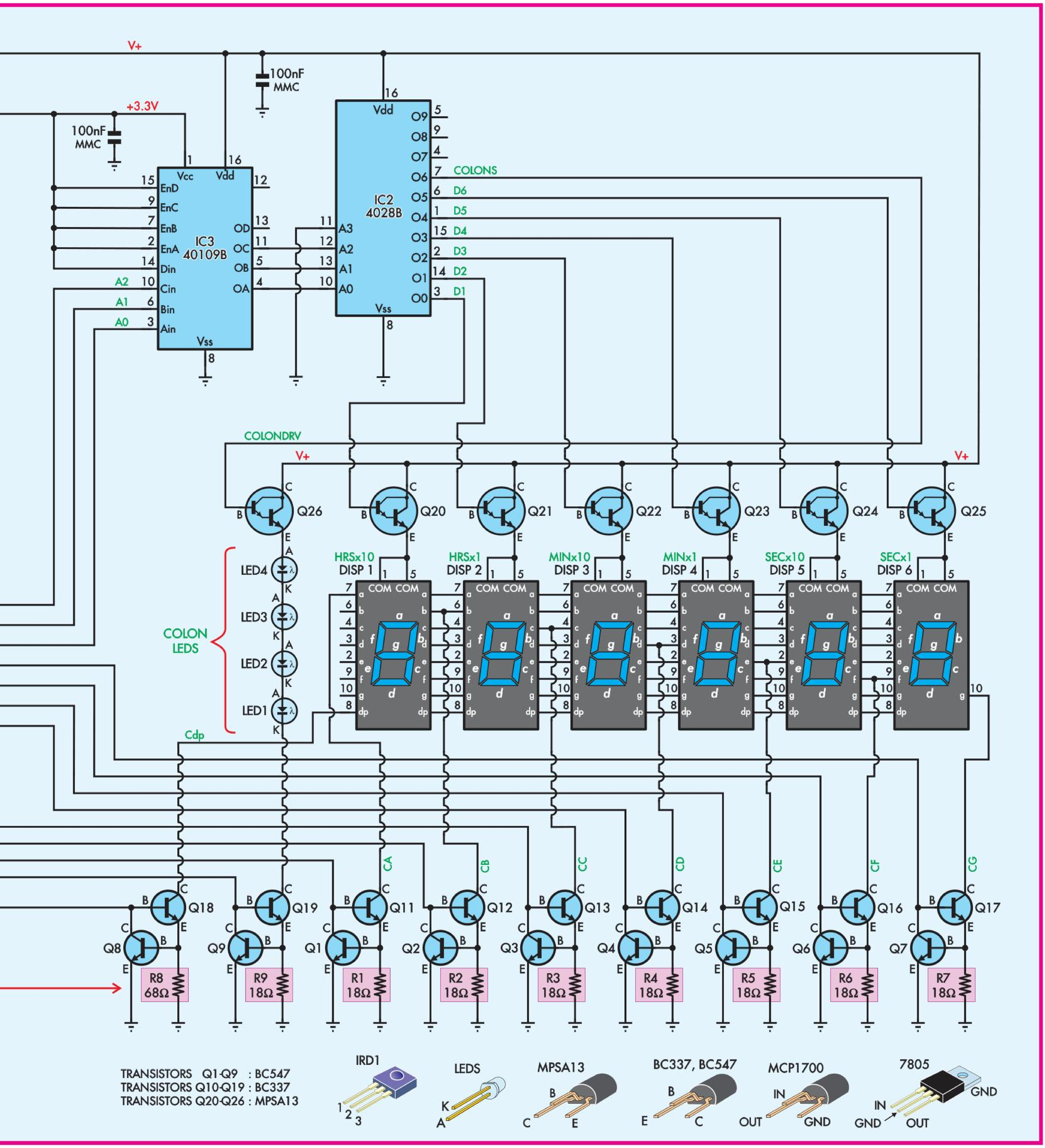
SIX LED DIGIT GPS DISCIPLINED CLOCK

Fig.1: the LED clock circuit is based around 32-bit microcontroller IC1. It drives the 7-segment display anodes via level shifter IC3, decimal decoder IC2 and Darlington transistors Q20-Q26. The cathodes are driven by NPN transistors Q1-Q9 and Q11-Q19. The power supply includes 5V and 3.3V rails to run the optional GPS module, plus a supercapacitor-backed 3.3V rail for the microcontroller.

off. Output pins O0-O5 select digits DISP1-DISP6, while output pin O6 drives Darlington Q26, which powers the four discrete colon LEDs.

Each of the seven-segment cathodes, including the decimal point, is switched by the micro, using a separate control pin to power an NPN transistor (Q11-Q18) operating as a common-emitter amplifier. These are combined with emitter resistors and additional NPN transistors (Q1-Q8) which limit the current through each segment when that segment is enabled.

For example, if segment A of the current digit is to be lit, output RB11 (pin 22) of microcontroller IC1 is driven high. This provides base current to Q11, which sinks current from the segment. an LED string within that digit. Once this current rises to approximately


V+
+3.3V
100nF MMC
100nF MMC
IC3 40109B
Vcc
Vdd
EnD
EnC
EnB
EnA
Din
Cin
Bin
Ain
Vss
OD
OC
OB
OA
A2
A1
A0
IC2 4028B
Vdd
Vss
A3
A2
A1
A0
O9
O8
O7
O6
O5
O4
O3
O2
O1
O0
COLONS
D6
D5
D4
D3
D2
D1
COLONDRV
Q26
Q20
Q21
Q22
Q23
Q24
Q25
HRSx10 DISP 1
HRSx1 DISP 2
MINx10 DISP 3
MINx1 DISP 4
SECx10 DISP 5
SECx1 DISP 6
COM COM
LED4
LED3
LED2
LED1
COLON LEDS
Cdp
CA
CB
CC
CD
CE
CF
CG
Q18
Q19
Q11
Q12
Q13
Q14
Q15
Q16
Q17
Q8
Q9
Q1
Q2
Q3
Q4
Q5
Q6
Q7
R8 68Ω
R9 18Ω
R1 18Ω
R2 18Ω
R3 18Ω
R4 18Ω
R5 18Ω
R6 18Ω
R7 18Ω
TRANSISTORS Q1-Q9 : BC547
TRANSISTORS Q10-Q19 : BC337
TRANSISTORS Q20-Q26 : MPSA13
IRD1
LEDS
MPSA13
BC337, BC547
MCP1700
7805
K
A
B
C
E
IN
OUT
GND

30mA, there is enough voltage across the 18Ω emitter resistor to forward-bias Q1's base-emitter junction, shunting any additional base-driven current away from Q11 and to ground.

Since the decimal points are physically smaller than the other segments, the associated emitter resistor value is higher (eg, 33Ω), reducing the relative current and thus providing visually similar brightness levels. The colon LEDs have a similar cathode-driving arrangement, although since they can be controlled entirely by switching the anode supply, this is not controlled by the micro, but rather enabled as long as the DC supply is present.

Timekeeping

The digits are multiplexed at 100Hz by micro IC1, to avoid noticeable

Parts List: High-Visibility 6-Digit LED GPS Clock

- 1 double-sided PCB with plated through-holes, available from the *EPE PCB Service*, coded 19110151, 302 × 70mm
- 1 set of laser-cut transparent acrylic pieces to make case*
- 1 acrylic adhesive – see Part 2
- 1 3.3V or 5V GPS module (optional; up to 200mA draw, TTL interface preferred)
- 1 mini TO-220 flag heatsink (6073B type, for REG1)
- 1 8-way pin header, 2.54mm pitch, snapped into 3-pin and 5-pin sections (CON3,LK1)
- 1 jumper shunt (LK1)
- 1 32.768kHz watch crystal (X1)
- 1 mini 9-14V piezo buzzer, 7.62mm pin spacing (PB1)
- 1 47-100kΩ LDR (LDR1)
- 2 right-angle tactile switches, 4.5mm-long actuators (S1,S2)
- 1 28-pin narrow DIL socket
- 2 40-pin socket strips
- 1 PCB-mount DC socket to suit power supply
- 1 M3 × 10mm machine screw, flat and shakeproof washer plus nut
- 4 4G × 6-9mm self-tapping countersink head screws
- 1 60mm length foam-cored double-sided tape (optional, for attaching GPS module)
- 4 small stick-on rubber feet (optional, for desktop usage)
- 1 universal remote control

Semiconductors

- 1 PIC32MX170F256B-I/P 32-bit microcontroller programmed with 1911015A.hex (IC1)
- 1 HEF4028 BCD to decimal decoder CMOS IC (IC2)
- 1 40109B CMOS quad level-shifter IC (IC3)
- 1 3.3V infrared receiver (IRD1)
- 1 7805 5V 1A linear regulator (REG1)
- 2 MCP1700-3.3/TO micropower 250mA 3.3V LDO regulators (REG2,REG3)
- 9 BC547 NPN transistors (Q1-Q9)
- 10 BC337 NPN transistors (Q10-Q19)
- 7 MPSA13 30V 1.2A NPN Darlington transistors (Q20-Q26)
- 1 13V 1W zener diode (ZD1)
- 2 1N5819 1A 40V Schottky diodes (D1, D2)

Capacitors

- 1 1F 5.5V supercapacitor
- 6 100μF 25V electrolytic, maximum height 11mm
- 1 10μF 4V SMD ceramic (1206) or tantalum SMD/through-hole capacitor
- 5 100nF disc or multilayer/monolithic ceramic
- 2 22pF disc ceramic

Resistors (0.25W, 1%)

- 1 100kΩ
- 4 10kΩ
- 2 6.8kΩ (one optional, for RS-232 GPS modules)
- 9 1kΩ
- 1 100Ω
- 3 22Ω 0.5W
- 1 10Ω

Additional parts

Blue display version

- 6 LBT23101BB blue 2.3-inch 7-segment LED displays* (DISP1-6)
- 4 5mm blue LEDs with diffused lenses* (LED1-4)
- 8 18Ω 0.25W resistors (R1-R7,R9)
- 1 68Ω 0.25W resistor (R8)
- 1 15-18V DC 500mA+ regulated power supply

Green display version

- 6 LBT23101BGG emerald green 2.3-inch 7-segment LED displays* (DISP1-6)
- 4 5mm emerald green LEDs with diffused lenses* (LED1-4)
- 8 18Ω 0.25W resistors (R1-R7,R9)
- 1 68Ω 0.25W resistor (R8)
- 1 15-18V DC 500mA+ regulated power supply

Additional parts continued

Red display version

- 6 CAI23101BS or SA23-11SRWA red 2.3-inch 7-segment LED displays* (DISP1-6)
- 4 5mm bright red LEDs with diffused lenses (LEDs1-4)
- 8 18Ω 0.25W resistors (R1-R7,R9)
- 1 68Ω 0.25W resistor (R8)
- 1 12-15V DC 1A regulated plugpack or 12V power supply

White display version

- 6 LBT23101BW white 2.3-inch 7-segment LED displays (DISP1-6)
- 4 5mm white LEDs with diffused lenses (LED1-4)
- 8 18Ω 0.25W resistors (R1-R7,R9)
- 1 68Ω 0.25W resistor (R8)
- 1 15-18V DC 500mA+ regulated power supply

Yellow-green display version

- 6 LBT23101BG green 2.3-inch 7-segment LED displays* (DISP1-6)
- 4 5mm bright green LEDs with diffused lenses (LEDs1-4)
- 7 5.6Ω 0.25W resistors (R1-R7)
- 2 22Ω 0.25W resistors (R8,R9)
- 1 15-18V DC 500mA+ regulated power supply

Yellow display version

- 6 LBT23101BY yellow 2.3-inch 7-segment LED displays (DISP1-6)
- 4 5mm yellow LEDs with diffused lenses (LED1-4)
- 7 5.6Ω 0.25W resistors (R1-R7)
- 2 22Ω 0.25W resistors (R8,R9)
- 1 15-18V DC 500mA+ regulated power supply

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flicker. Crystal X1 is used to run its internal real-time clock and calendar (RTCC) for timekeeping. If a GPS receiver is connected via CON2, its serial data stream is received by IC1 at pin 24 and once sufficient data is available to determine accurate local time, the RTCC is updated and kept synchronised with the GPS data.

If the unit loses power, the GPS unit is powered down as it is supplied by either REG1 (if it runs off 5V) or REG3 (3.3V) and these are powered from the incoming ~15V supply from CON1 via D1. However, a 1F (one-farad) super capacitor is charged from REG1's output via Schottky diode D2, to around 4.7V. This capacitor powers micropower low-dropout 3.3V regulator REG2, which supplies microcontroller IC1 and the GPS unit's memory back-up (if required).

The micro detects a loss of power by monitoring the voltage at its AN1 input. If the 15V rail drops below 7V (the voltage required to keep the supercap charged), it immediately switches off all the LEDs and goes into a low-power sleep mode while keeping its RTCC active. It wakes up every few seconds to check if power has been restored and if so, resumes displaying the time.

If a GPS receiver is present, after some time (usually a minute or so), it will regain satellite lock and the time will be re-synchronised. However, given that the supercap charge will only last a few hours, it's unlikely the RTCC will have drifted more than a small fraction of a second during this time.

Infrared receiver IRD1's output is connected to input RB1 of IC1 (pin 5) and so a universal remote can be used to set the time and control the unit, allowing it to be used as a timer as well as a clock. The remote can also be used to set an alarm. In the absence of a remote control, pushbuttons S1 and S2 can be used to perform basic tasks such as setting the time. When pressed, these pull down inputs RB5 and RB6 (pins 14 and 15) which are also used initially to program IC1 via CON3.

IC1 can activate a piezo buzzer by bringing its RA3 output (pin 10) high. This supplies current to the base of NPN transistor Q26, which then sinks current from the buzzer's negative terminal. ZD1 limits the voltage applied across the buzzer, while the current through Q10 is limited to a safe level by its 6.8kΩ base resistor.

Microcontroller IC1 uses LDR1 to monitor the ambient light level and adjust the LED brightness to suit. LDR1 forms a voltage divider across the 3.3V supply in combination with a 10kΩ resistor and thus the voltage at pin 2 of IC1 (AN0) varies depending on the amount of light falling on LDR1. The top of this divider is connected to REG3 so it doesn't draw power from the supercap via REG2 when the main supply is off.

REG1 is fitted with a flag heatsink; while the circuit does not draw a great deal of current from the regulator, the voltage across it can exceed 10V. The two 22Ω resistors in series with the input reduce regulator dissipation by up to half a watt. D1 provides reverse supply polarity protection while minimising voltage drop.

Most LED displays we tested worked best when the clock was driven by a regulated DC supply of 15-18V. Lower voltages can be used, down to around 12V (depending on the exact displays used), however maximum brightness and display uniformity may not be quite as good. For lower supply voltage, red is the safest display choice.

Software operation

The micro's hardware real-time clock and calendar (RTCC) is used for timekeeping, in combination with an external 32.768kHz crystal. If a GPS unit is present, when a valid time is received via the serial port, it is compared against the RTCC, which is moved forward or back if necessary to keep correct time.

Display multiplexing is performed using a timer interrupt so that if the micro is busy doing some processing (eg, geographic searching to determine your time zone) it won't interfere with the display. Infrared reception is similarly interrupt-based; however, this uses a pin change interrupt as well as a timer to measure infrared pulse duration.

For details on how the GPS latitude/longitude information is used to search an extensive geographic database for time zone determination, see the explanation on pages 28 and 29 of the February 2016 issue. We re-used this part of the code from the *Nixie Clock* project, along with the geographic data. There were some bugs in the original *Nixie Clock* code in handling some time zones and the fixes have been incorporated into this project.

We used some other lessons learned in the design of the *Nixie Clock* when designing this project. For example, we've connected the LDR to the 3.3V supply, which is not derived from the 1F supercapacitor, to increase the time that the supercap lasts in a blackout. We changed D2 to a Schottky type for the same reason. Originally, we used a standard diode for this role due to the much lower reverse leakage, but it turns out that the lower forward voltage of the Schottky diode more than makes up for this.

Choosing a GPS module

You need a GPS module that will fit in the space available but also with good sensitivity as it must work well indoors. Many such modules are available at surprisingly low prices.

The GlobalSat EM408 we used in our prototype (US$17.81) has a tracking sensitivity of –159dBm, while the more expensive Fastrax UP501 is –165dBm (ie, better). We found a VK16E (–159dBm) on Ali Express for US$8.79 and a u-blox Neo-6M (–161dBm) for US$10.42.

Other differences between modules are: TTL or RS-232 signalling, 4800 or 9600 baud, whether it has an on-board battery back-up, whether it has a 1PPS output and whether there's an enable pin and how it's driven. TTL is preferred over RS-232 as RS-232 requires a resistor to be added in series with the TX pin of the module. The software will automatically detect the baud rate.

Whichever module you choose, you will need to check the data sheet to determine these factors and its pinout.

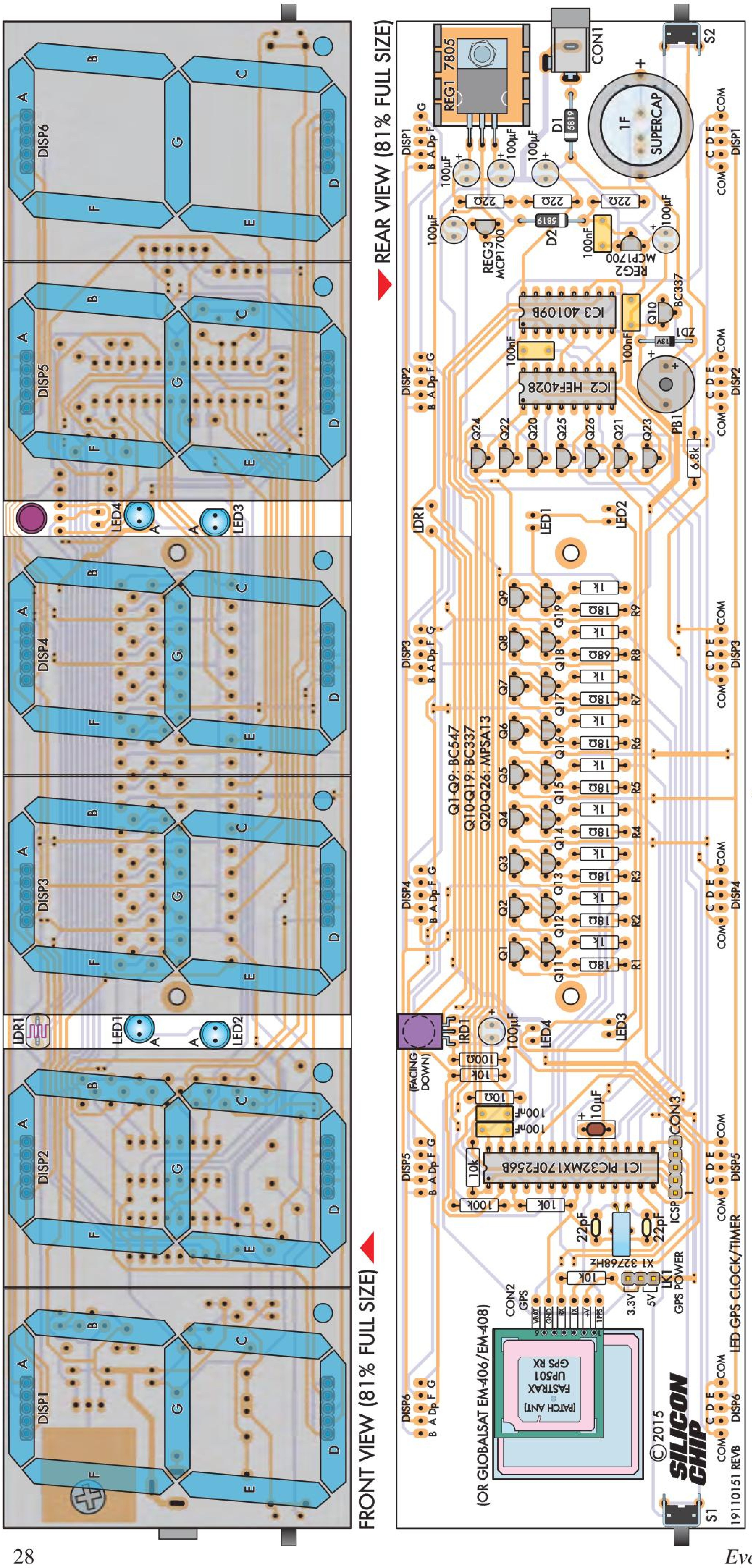
A 1PPS output is desirable and gives the most accurate time, but is not vital. Onboard battery back-up will let the module ride out longer black-outs, but modules without can have VBAT connected to the supercap so that it doesn't have to go through a slow cold-start each time it powers up.

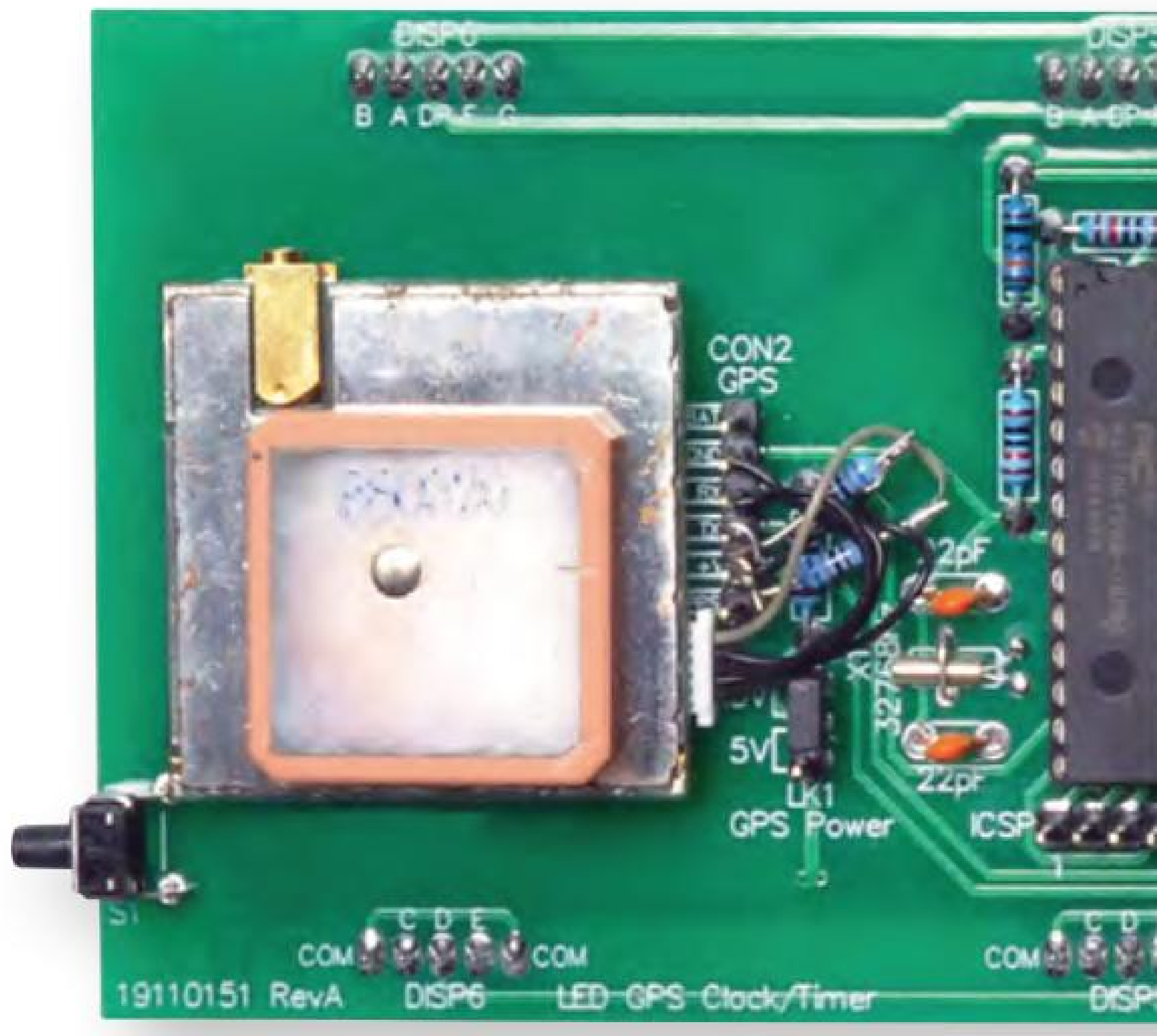
Many modules have no enable pin, or if they do, it may be left floating. However, the EM408 we used required a pull-up resistor between its enable input and its power supply, so we soldered one onto the pin header. It looks a bit messy but does the job.

Construction

The first step in the assembly is to fit the control components to the back of the PCB, as shown in Fig.2. Start with the resistors; it's best to check each batch with a DMM before fitting them. Remember to change the resistor values to suit the display colour you're using (see parts list).

Follow with the two Schottky diodes, oriented as shown in Fig.2, then zener diode ZD1. Then fit the socket for IC1, with the notch at the top as shown. The watch crystal can go in next; be careful, since its leads are very thin. Bend them so that the crystal can lie flat on the board without the leads touching the metal can and solder a


REAR VIEW (81% FULL SIZE)
FRONT VIEW (81% FULL SIZE)
DISP1
DISP2
DISP3
DISP4
DISP5
DISP6
A
B
C
D
E
F
G
LDR1
LED1
LED2
LED3
LED4
REG1 7805
CON1
S1
S2
D1 5819
D2 5819
1F SUPERCAP
REG2 MCP1700
REG3 MCP1700
IC1 PIC32MX170F256B
IC2 HEF4028
IC3 40109B
Q10 BC337
ZD1 13V
PB1
6.8k
Q1-Q9: BC547
Q10-Q19: BC337
Q20-Q26: MPSA13
R1
R2
R3
R4
R5
R6
R7
R8
R9
18Ω
68Ω
1k
22Ω
100µF
100nF
10µF
22pF
10k
100k
100Ω
10Ω
IRD1
(FACING DOWN)
CON3
ICSP
X1 32768Hz
LK1
GPS POWER
3.3V
5V
CON2 GPS
VBAT
GND
RX
TX
5V
1PPS
FASTRAX UP501 GPS RX
(PATCH ANT)
(OR GLOBALSAT EM-406/EM-408)
©2015
SILICON CHIP
19110151 REVB
LED GPS CLOCK/TIMER
B A Dp F G
C D E
COM


DISP6
CON2 GPS
LK1
GPS Power
ICSP
22pF
S1
COM
C D E
19110151 RevA
LED GPS Clock/Timer

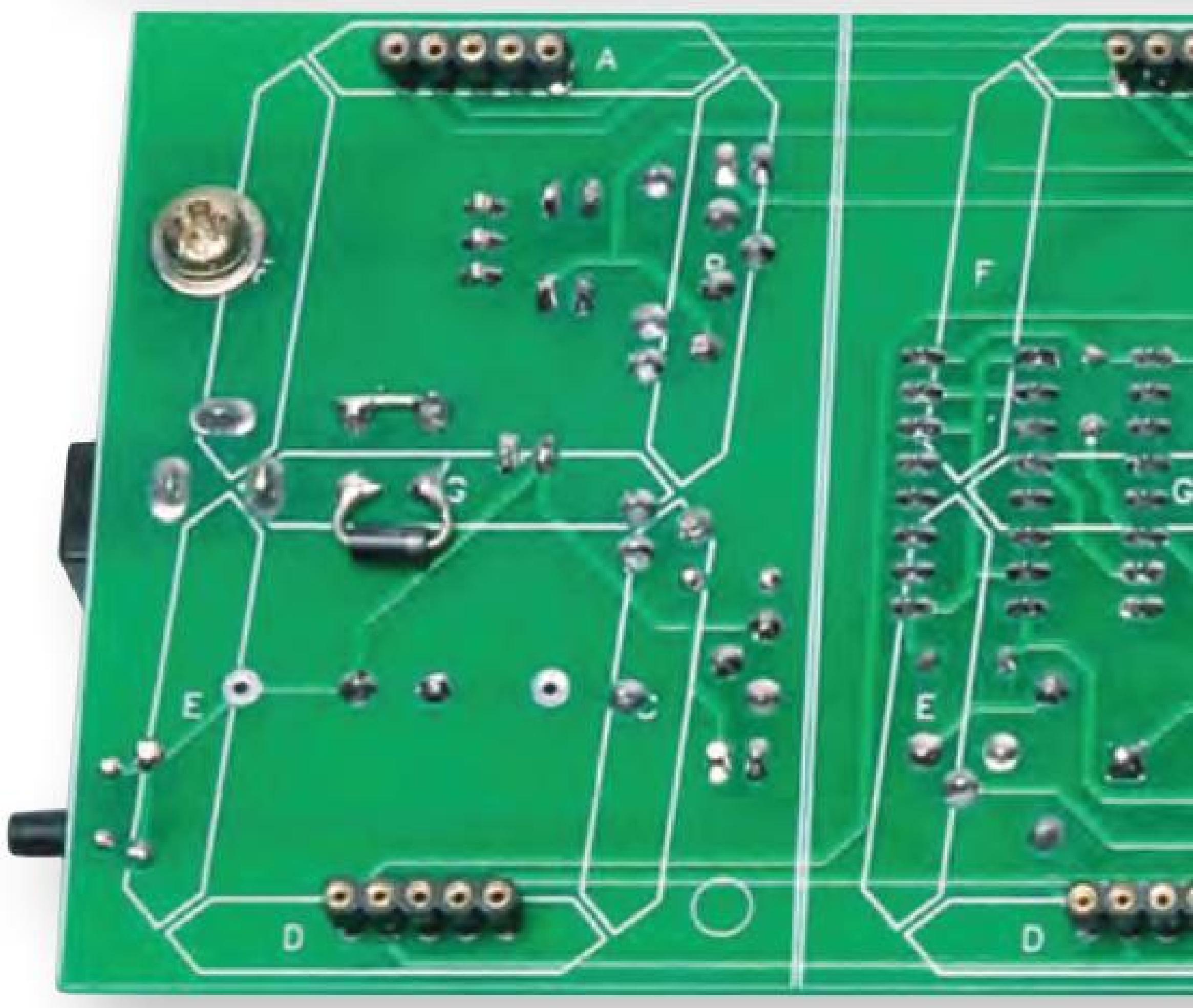
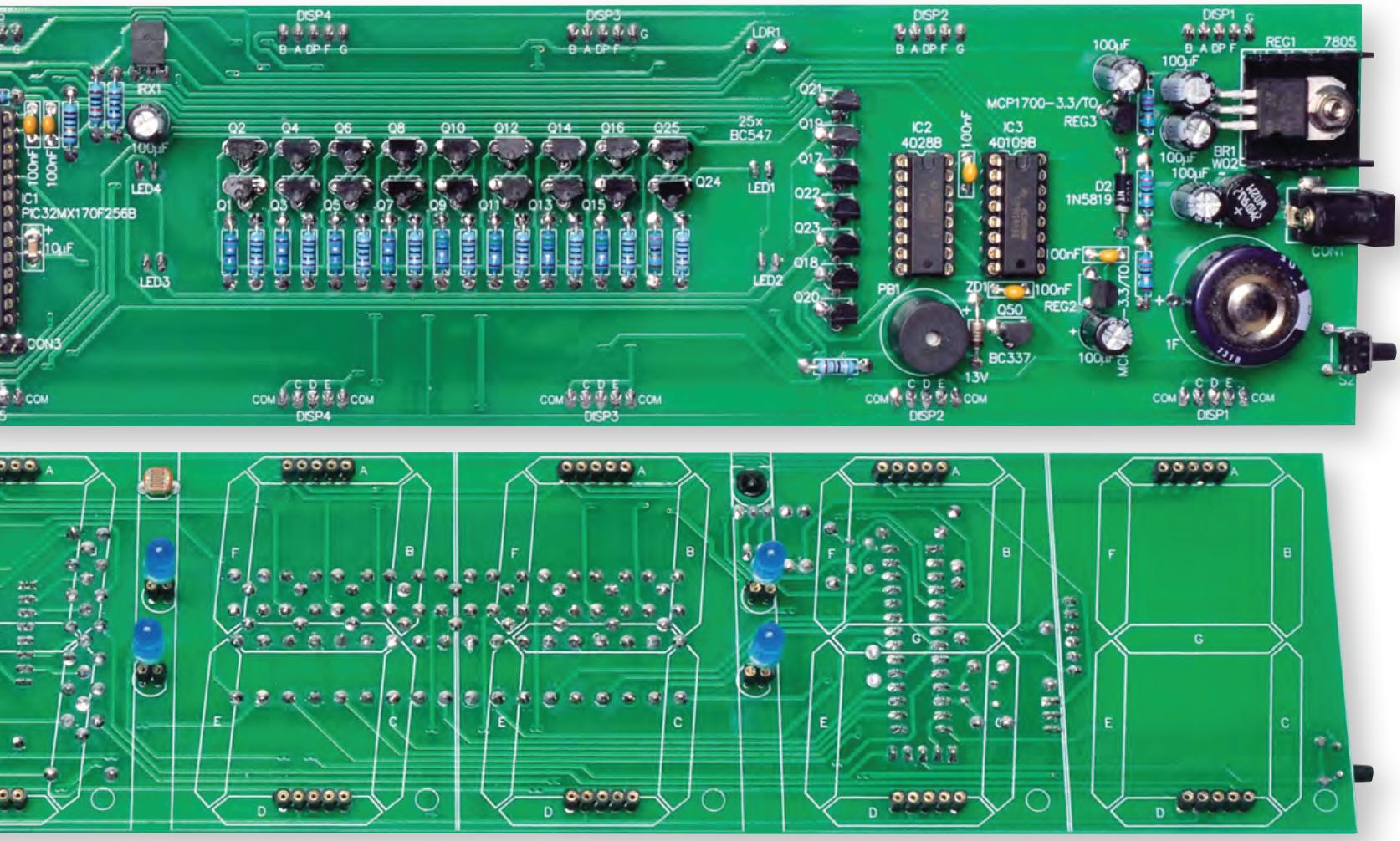


Fig.2: most of the components are fitted to the rear of the PCB. Note that the values of resistors R1-R9 are varied to suit the 7-segment LED displays used and that the 10µF capacitor can be either an SMD ceramic (as in our photos and recommended) or a through-hole tantalum type. The six large displays are mounted on the front of the PCB via socket strips, along with the LDR for ambient light sensing and four discrete LEDs which form the colons between the hours, minutes and seconds. IRD1 is mounted on the back of the PCB but 'peers' through a hole between the minutes and seconds displays.

resistor lead off-cut to the pads on either side after bending it tight over the can to hold it down.

Next, bend REG1's leads down by 90° exactly 5mm from its body and attach it to the PCB with a flag heatsink wedged in-between. The head of the M3 machine screw goes on the other side of the PCB, with a flat washer under the screw head and a shakeproof washer under the nut.

Do the screw up tightly and make sure that the heatsink is straight and that the regulator pins pass through the appropriate mounting holes



Above: compare these photos with the layout diagrams (Fig.2) when building the unit. Note that our prototype used an RS-232 GPS module. This meant that we had to install a couple of extra 6.8kΩ resistors (see text).

before soldering and trimming the three leads.

Now solder IC2 and IC3 in place. Be very careful to get the orientation correct (pin 1 at upper-left) and don't get them mixed up as it's very difficult to de-solder DIL ICs from a plated-through board. You could use sockets, as we did for our prototype, however direct soldering provides better reliability.

The ceramic capacitors can go in next, followed by the transistors. There are 26 in total and three different types, so don't get them mixed up. Fig.2 shows the position and orientation of each. You will probably need to crank the leads out in each case, which is easy to do with a small pair of pliers. The two MCP1700 regulators can then go in, using the same procedure.

Now fit the two pushbuttons at either end of the PCB, making sure they are pushed all the way down onto the board before soldering them. Follow with the DC socket (the same comment applies). The two pin headers can then be soldered in place, followed by the remaining capacitors.

Watch the electrolytic and tantalum (if used) capacitor polarity, especially the supercap, as you may need to check its markings carefully to figure out which terminal is positive and which is negative. Three sets of holes are provided for the supercap, to suit different lead spacings. Mount the piezo buzzer now; it's also polarised and the plus symbol on the PCB shows how it is oriented.

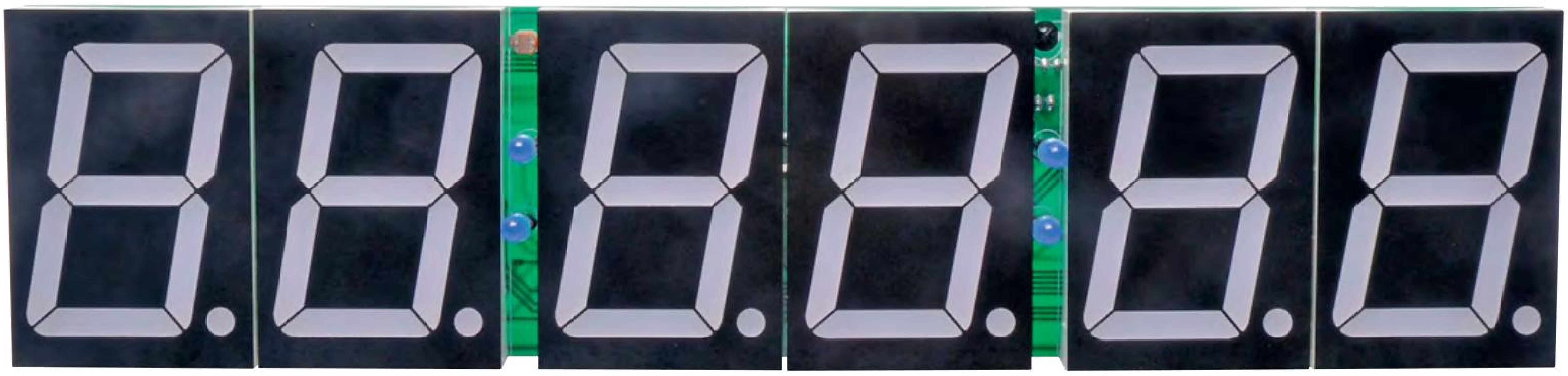
Infrared receiver IRD1 is mounted on the same side of the PCB as the other components installed so far; however, it's flush against the PCB and 'looks' through the adjacent hole. Bend its leads down very close to the body, towards the lens, but don't let them actually touch the body as it may be made of conductive plastic. Push it down so that the lens protrudes through the hole in the PCB as much as possible, then solder and trim the leads.

Assuming you are fitting a GPS module, attach it in the mounting location provided using doubled-sided tape, with the ceramic patch antenna at the top, and solder the four, five or six wires to the adjacent pads. Refer to Fig.2 to see which wires go where. All modules will need the GND, RX, TX and V+ wires connected. Modules with a 1PPS output should also have that wire connected and if the module requires a RAM back-up supply, connect it to the 'VBAT' pad.

Place the jumper shunt on LK1 to select either the 3.3V or 5V supply as needed. (If your module will run off both, use the 3.3V supply). **As mentioned earlier, if your GPS module uses RS-232 levels, you will need to solder a series resistor of around 6.8kΩ between the module and the TX pad on the PCB or IC1 could be damaged.**

We used an RS-232 EM408 module in our prototype, so we soldered two resistors to CON2, one from +V to pull its enable pin high and one in series with the TX pin as mentioned above.

Next, plug IC1 into its socket. Make sure its orientation is correct. If your chip is not already programmed, you can connect a PICkit 3 (or similar) to CON3, the ICSP header. Switch on the



Above: the 7-segment LED displays plug into sets of 5-way SIL sockets, as shown on Fig.2. Make sure that the displays are all correctly oriented (ie, decimal points at bottom right).

LED display characteristics

The six 7-segment digits which form the clock display are in separate modules measuring 48 × 70 × 12mm, each with 10 pins. The digits themselves are 57mm tall and 32mm wide. Each segment consists of four series LEDs, except for the decimal points, which comprise two series LEDs. Two of the 10 pins are the common-anode connections, while the remaining eight are the separate cathodes for each segment.

In our clock, the colons between the digits are formed from discrete 5mm LEDs which are chosen to have a similar colour and brightness to the digit segments.

Most 7-segment display data sheets lack good data on the LED characteristics, which is important to determine how best to drive them. We purchased a number of compatible 7-segment modules in various colours and tested them. Some of these came from long-established LED manufacturer Kingbright, while others came from Chinese factories.

While it may seem surprising, overall we found the Chinese-sourced displays to give the best results, offering very high and even brightness at a reasonable price. These are available in the Silicon Chip On-line Shop for readers who wish to build a clock using these units – see Parts List.

The results of our measurements are shown in Fig.3. This shows the forward voltage of the four series LEDs in one segment from each display, along with the current flow for that voltage. The dot on each curve shows the point at which we considered the light output to be subjectively bright and gives some idea of how hard each display type would have to be driven to achieve a sufficient brightness level.

The LBT23101BG curve has no dot because it did not achieve what we would consider to be a sufficient brightness level, even at 100mA! These also showed a dramatic colour shift towards red at higher DC currents so we would not recommend these be used, especially for a multiplexed display like this one.

As expected, the blue LEDs have the highest forward voltage (a typical blue LED has a voltage drop of 3-3.6V) while the red LEDs have the lowest and thus would be suitable for use with a 12V supply, such as in a car or caravan. Green and yellow LEDs tend to fall in-between. We didn't test white displays but we expect they would have similar characteristics to the blue types.

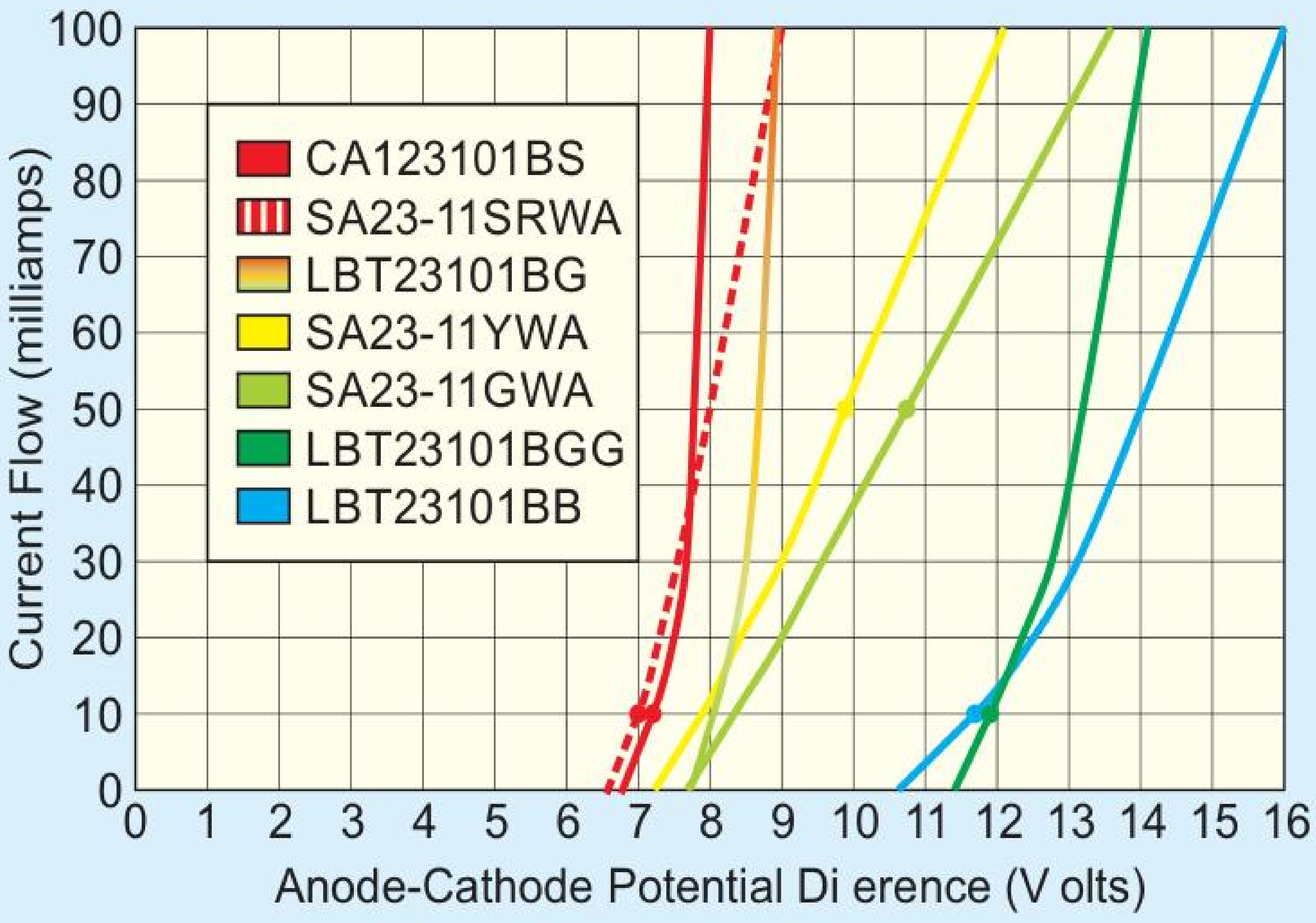


Fig.3: voltage/current curves for various types of 2.3-inch 7-segment LED displays. The SA23 types are from Kingbright, while the others are from various Chinese LED factories. The dots on each curve indicate the current level at which high brightness is apparent. Note the dramatic colour shift with current of the LBT23101BG.

There were some surprises in the results. Of the green displays, the most expensive were the 'emerald green' types and these have a colour more towards the blue end of the spectrum, while the standard green types are more yellow. As you can see, the emerald green LEDs have quite similar characteristics to the blue LEDs, with a high forward voltage, but they are also extremely bright, even at low currents. This, combined with the pleasant shade of green and good colour consistently would make them our first choice for building a green LED clock.

Our conclusions are as follows: the Kingbright SA23-11SRWA and Chinese CA123101BS are similar and both quite suitable red displays. Kingbright SA23-11YWA (yellow) and SA23-11GWA (green) are usable, but need to be driven right to their instantaneous current limits for sufficient brightness.

For colours other than red, the Chinese-sourced LBT-23101BGG (emerald green) and LBT23101BB (blue) look excellent; however, they require a 15-18V supply to get a good and consistent brightness level.

PICkit's internal 3.3V power supply and program the chip.

Alternatively, you could feed 12V DC into CON1; assuming the board has been built correctly, this should also allow you to program the chip.

Displays

The displays are not soldered to the PCB directly as this would block access to the solder joints for the remaining components, should one of them require replacement. Instead, they plug into socket strips. Snap or cut the socket strips into 12 lengths with five pins each. Do this carefully as the plastic surround can break off in the wrong place if you aren't careful. The overlay diagram for this side of the board is also shown in Fig.2.

Solder these on the opposite side of the PCB to the other components, at the top and bottom of each display location. Make sure they are all pushed down fully into the PCB and line up properly. Now trim the leads of all the displays to 5mm and plug them in. The easiest way to ensure the displays sit at a consistent level is to cut a 5mm-wide strip of cardboard and use this as a template while trimming the pins.

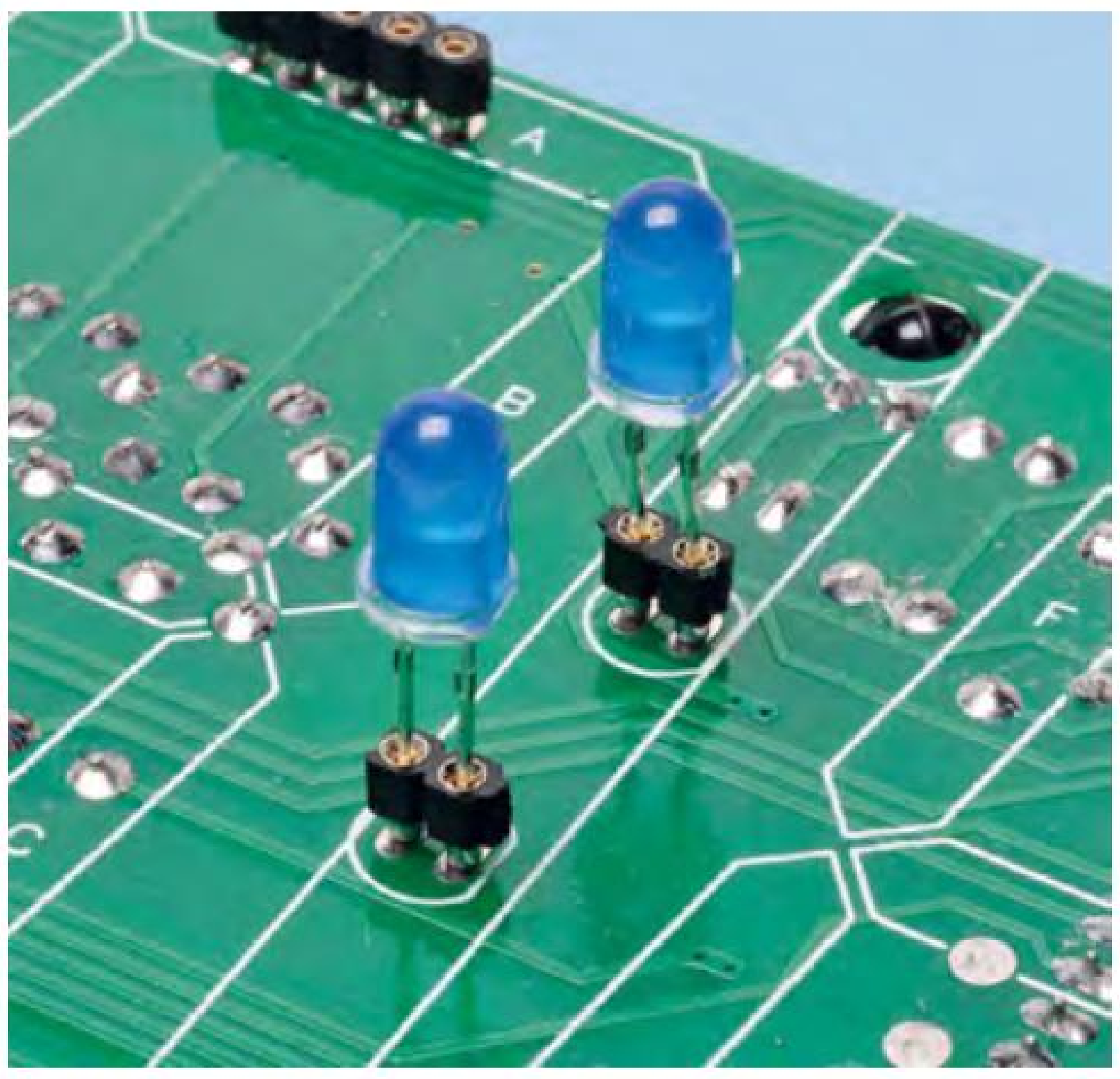
When plugged in, the back of each display should rest just above the top of the socket strips. Make sure the display orientation is correct, ie, the decimal points are all lined up along the bottom of the PCB.

Check that the distance from the front of the displays to the top of the tallest component on the other side of the board is no more than 30mm. If it's more than this, you will need to trim the display leads further. In practice, this means the top of each display should be just under 17mm from the PCB surface.

The LDR is located on the same side as the displays and fits between DISP2 and DISP3. Solder it a couple of millimetres above the surface of the PCB, just below the bottom edge of the displays.

The final components to install are the four LEDs that form the colons between the hours, minutes and seconds parts of the display (and flash at 1Hz). These are fitted so the domed parts of their lenses protrude above the top of the displays.

This requires them to be mounted so that their plastic bodies are 11mm above the PCB. You can achieve this by placing an 11mm-tall cardboard spacer between the leads and pushing the LED down so that bottom of its lens is in contact with the spacer. It's then just a matter of soldering and trimming the leads and sliding the spacer out. Make sure all four anodes (longer leads) are oriented towards the lefthand edge of the PCB, as shown in Fig.2. Similarly, the flat sides of the LEDs should go to the right.



For our prototype, we plugged the 5mm blue LEDs into short sections of socket strip cut from what was left after fashioning the sockets for the six digits. This makes it easier to try out different LEDs for the best colour match and viewing angle to go with the clock display.

For our prototype, we trimmed the LED leads shorter and plugged them in using short pieces of socket strip, as shown in the above photo. This allowed us to easily experiment with several different types of LED to find a good match for the 7-segment displays.

If you're using LEDs that we've supplied with the 7-segment displays, you don't need to do this but if using other LED types, it might be a good idea.

Note that the LED mounting locations are slightly staggered, so that the 'colons' they form line up with the slanted 7-segment digits. The 5mm LED lens domes protrude above the 7-segment displays so that they can be seen when the display is viewed at an angle; these poke through holes in the laser-cut case which hold them neatly in place despite the long leads.

That's all for this month. Next month, we'll go over testing the PCB, making the case, putting it all together and explain how to set up the remote control, set the time and use the various functions of the clock.

PoLabs

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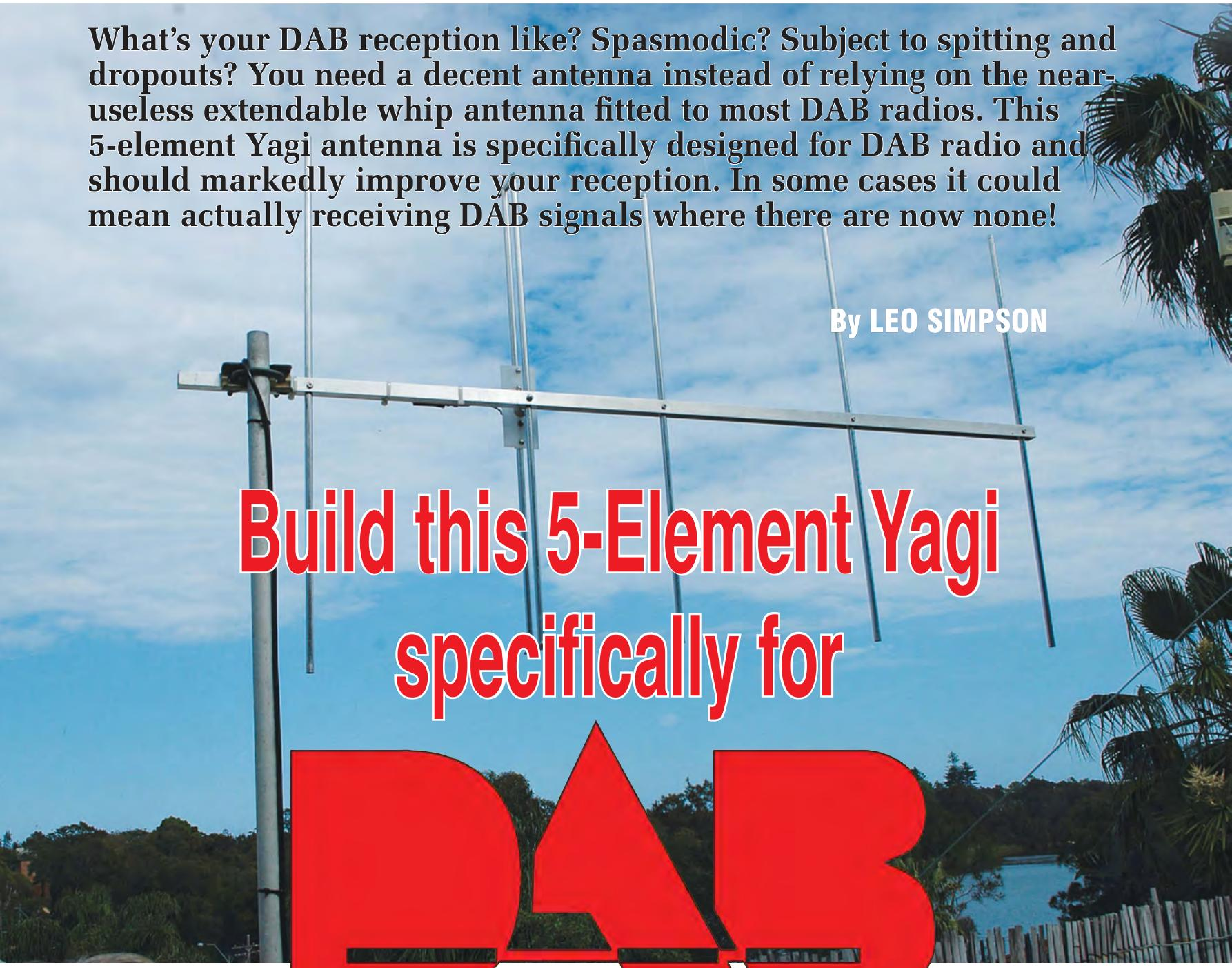


Build this 5-Element Yagi specifically for DAB Digital Audio Broadcasting

What's your DAB reception like? Spasmodic? Subject to spitting and dropouts? You need a decent antenna instead of relying on the near-useless extendable whip antenna fitted to most DAB radios. This 5-element Yagi antenna is specifically designed for DAB radio and should markedly improve your reception. In some cases it could mean actually receiving DAB signals where there are now none!

By LEO SIMPSON

Many people these days have DAB radios but they are often disappointed with the reception, even though they may live quite close to the transmitters.

They buy a DAB radio because they have been sold on the 'clean, clear digital sound' that it is supposed to have. But often, the results are less than expected, and this is mainly for two reasons.

First, virtually all DAB radios come with an extendable whip antenna which does double duty for FM and DAB reception. Truth is, these whip antennas are at best a compromise for either mode.

Nor do most DAB radios have an antenna socket into which you can plug an external antenna. So the average listener is stymied – even if they want to improve reception.

And the second reason why DAB sound quality is generally disappointing is the that digital data rate (ie, at the station) is simply too low for good quality sound.

This means that a station broadcasting on FM and DAB will typically sound much better on good old 'steam-driven' FM stereo multiplex transmissions. Even so, a DAB radio fed with a good signal will always have a quiet background, no 'spitting' and will sound quite clean to most ears.

So this article will describe how to build a good DAB antenna and also, tell you how to fit an antenna socket to your radio so you can feed the improved signal into it.

Vertical polarisation

DAB transmissions are usually vertically polarised. That means that any receiving antenna must also be vertically polarised. That brings about an important constraint about how the antenna is mounted on a metal mast, as we shall see shortly.

As with the *FM antenna* presented in the October 2016 issue, this is a 5-element Yagi design, but is half the size of the *FM antenna* because it operates at roughly twice the frequency.

The Yagi antenna presented in this article is designed to cover all the DAB bands in the UK. It has a measured gain of about +12dB with respect to a whip antenna. However, that figure is with respect to a dipole which has a ground plane. Unfortunately, the whip antennas in DAB radios do not have adequate ground planes so their performance is even worse.

With good 'line of sight' reception, a 5-element Yagi antenna like this should give reception at quite long distances from the transmitter, perhaps 100km or more. However, we have not tested this aspect. We can vouch for the gain figure though (as detailed later in this article).

Tools you will need

Most enthusiasts will have all the tools needed for this project. You will need a hacksaw, electric drill and a vice. It would also help if you have a drill press but you can do without this.

Apart from an antenna clamp (U-bolt and V-block), no special hardware or fittings are required.

Tube cutter

In October's article we noted that a tube cutter is a very handy tool in an antenna project such as this. You end up with smooth square cuts with no swarf. When using a cutter, it is important not to rush the job. Mark the position of the cut on the tube with an HB pencil and then position the blade of the cutter precisely on the mark, with the tube sitting between the rollers. Apply very light pressure with the knob of the cutter and then measure from the end of the tube to the blade of the cutter, to make sure you are cutting to the exact length you want.

Actually, if you have not used one of these cutters before, do a couple of practice cuts on scrap plastic conduit, just to get the feel of the whole procedure.

You are also likely to find that because the tube is very smooth and quite small in diameter, it is hard to get a grip on it as the cut deepens. Gripping the tube with a rubber kitchen glove makes it a lot easier.

The 'digital cliff'

Unlike analogue broadcast radio (AM or FM) but very similar to digital TV, with DAB radio you have either got a signal, or you haven't. There's virtually no middle ground!

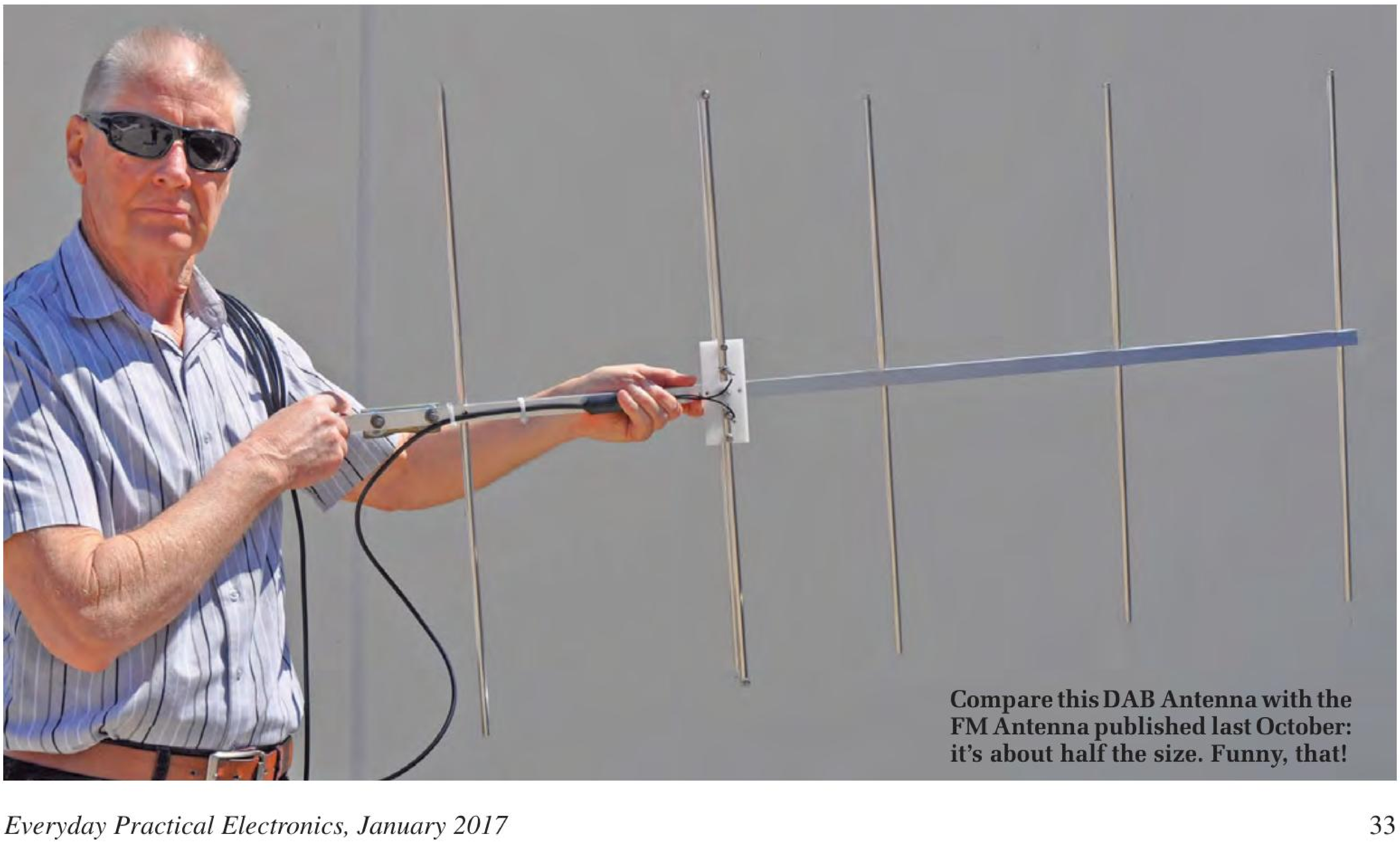
It's the dreaded 'digital cliff' – the metaphor is that if you don't have enough signal (or, perhaps surprisingly, too much signal causing overload) digital radio or TV falls off the cliff and you get nothing.

Of course, either digital radio or TV might be trying to tell you it's struggling, with continual dropouts and break-up when it's just on the point of teetering over the edge – most listeners or viewers would not tolerate this and turn off.

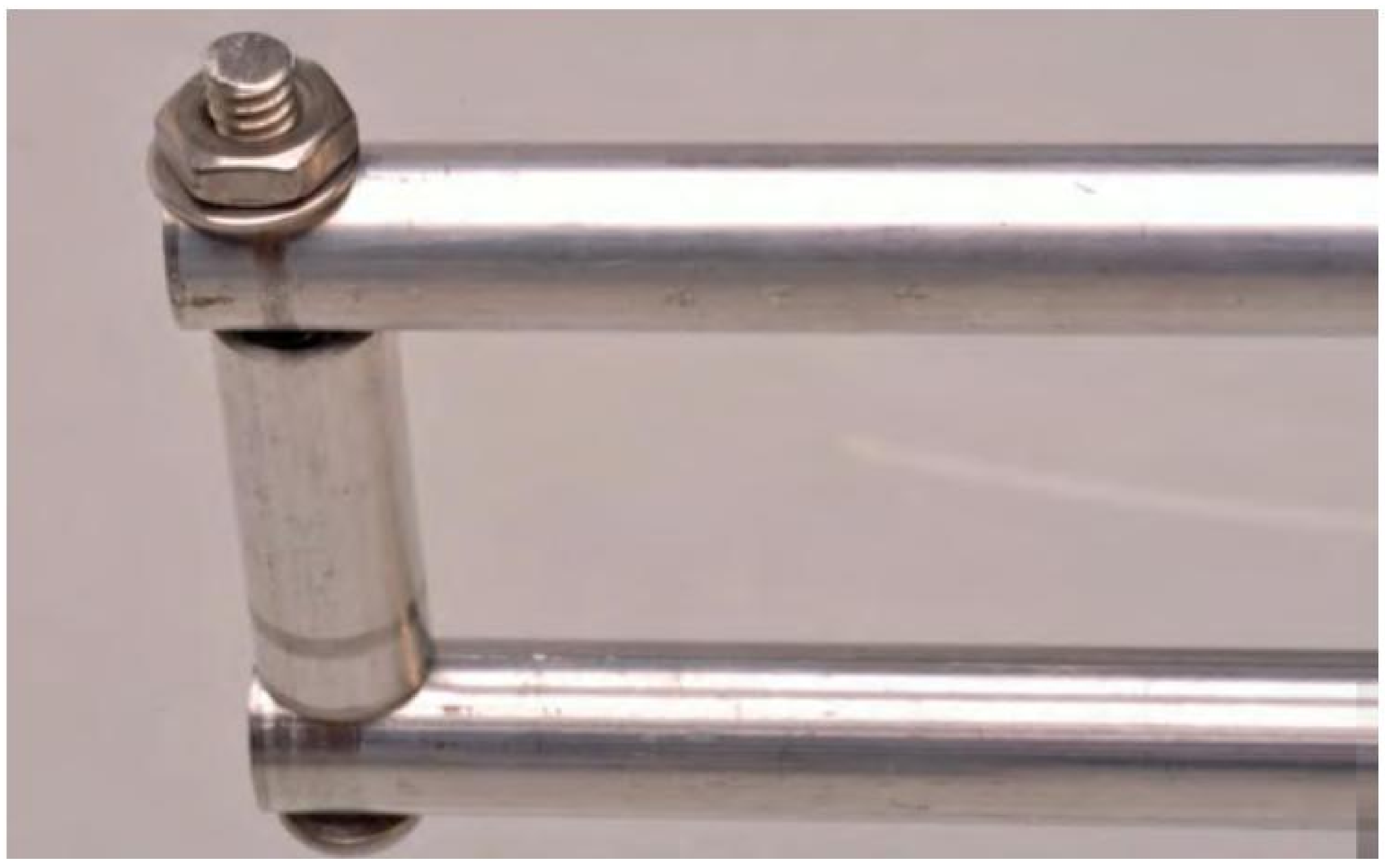
It's often found that weather can also push reception over the cliff.

The big advantage of this project is that the gain of the Yagi can lift your signal to the point where you get reliable levels; enough to give you good reception.

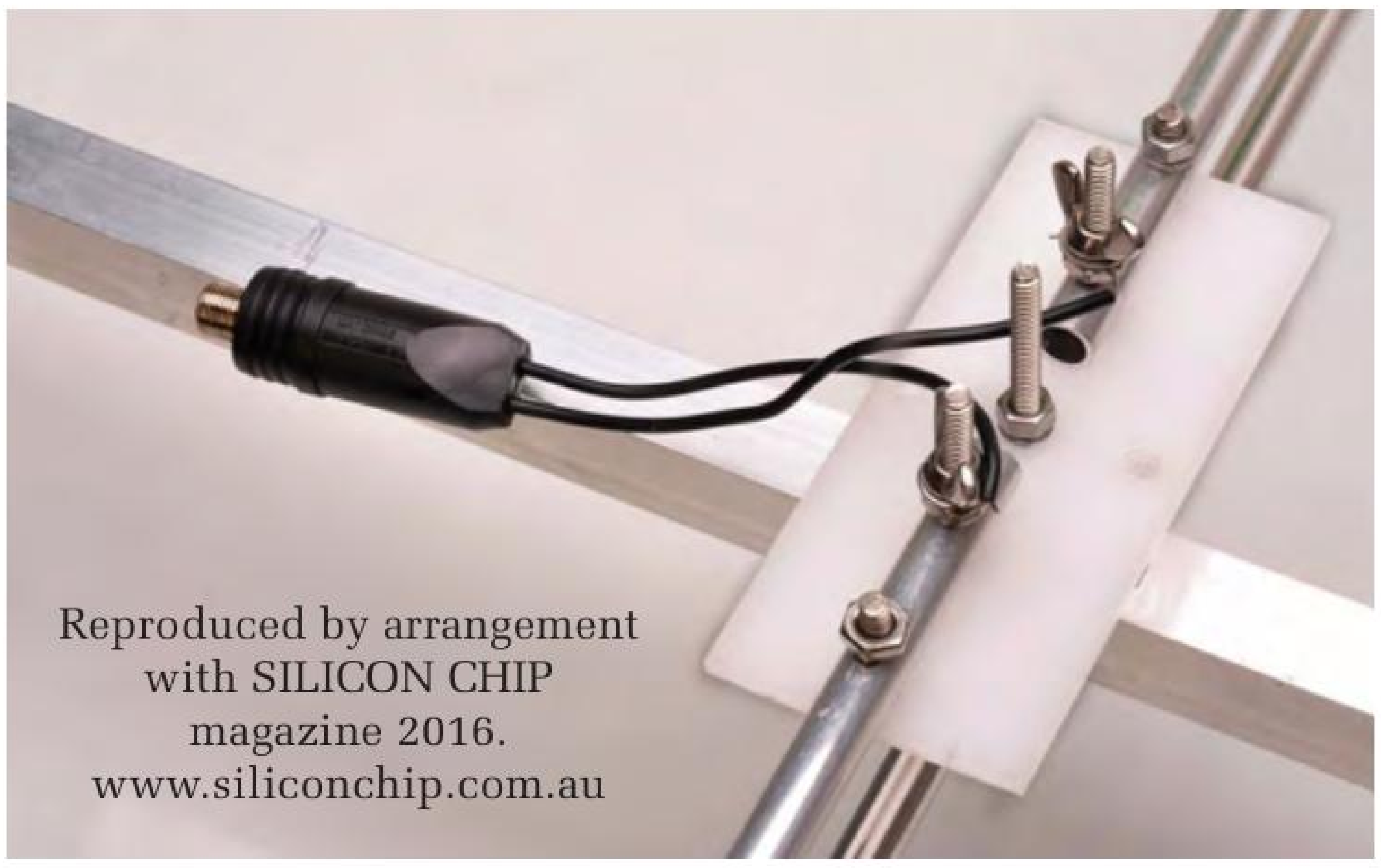
With 12dB of gain, we would expect this antenna to bring a lot more listeners into the DAB family!



Compare this DAB Antenna with the FM Antenna published last October: it's about half the size. Funny, that!



The ends of the folded dipole are fabricated using 42mm lengths of aluminium tubing shaped to mate with the upper and lower pieces. They are held together with 50mm-long machine screws, nuts and split washers.



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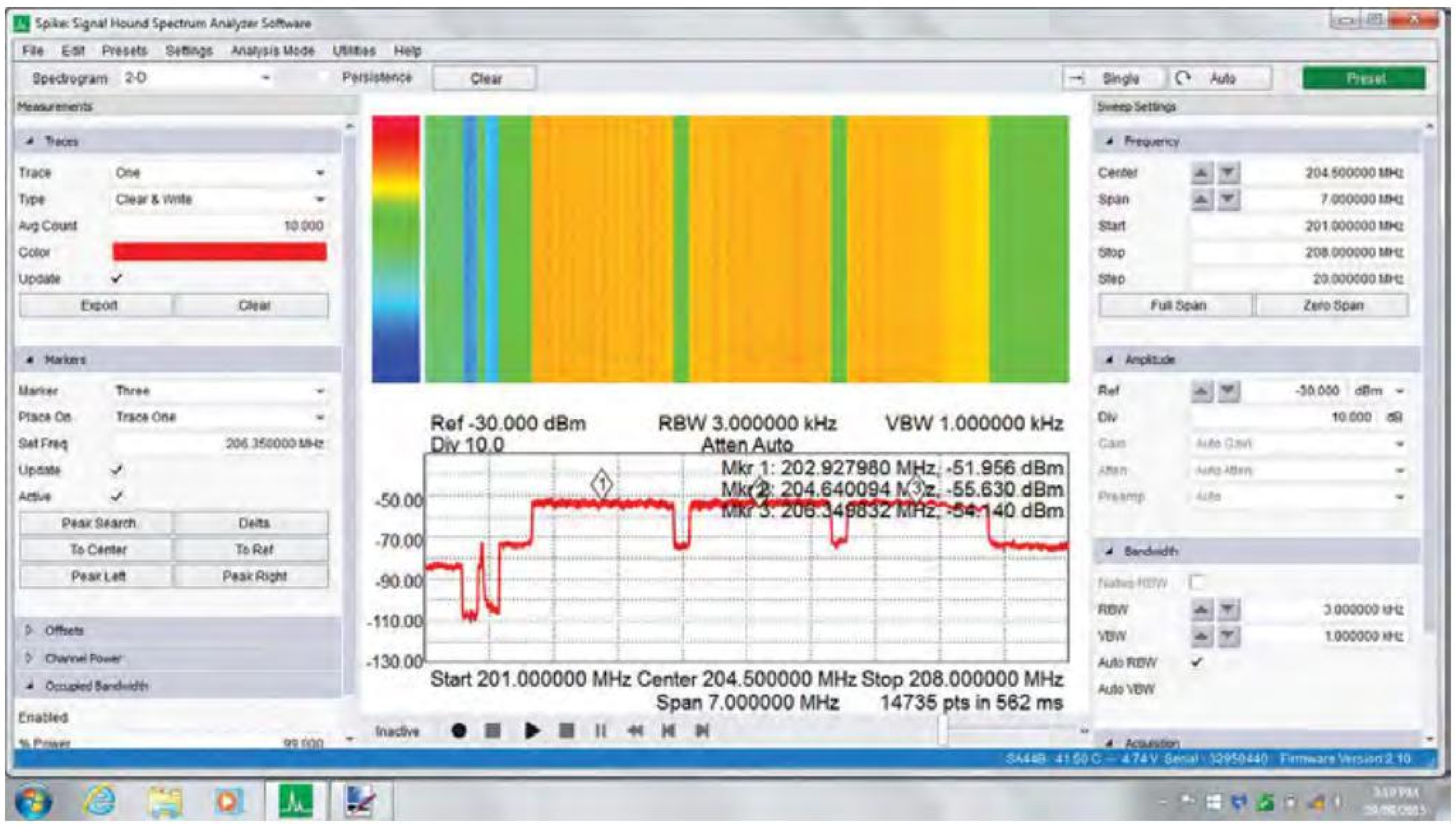
The dipole insulator plate has wing nut terminals to connect 300Ω ribbon or a 300Ω-to-75Ω balun. The plate is made from perspex, lexan or other acrylic material. The square boom makes mounting easy.



Spike: Signal Hound Spectrum Analyzer Software

Spectrogram 2-D

Trace One
Type Clear & Write
Avg Count 10.000
Update ✓

Marker Three
Place On Trace One
Set Freq 206.350000 MHz
Update ✓
Active ✓

Ref -30.000 dBm RBW 3.000000 kHz VBW 1.000000 kHz
Div 10.0 Atten Auto
Mkr 1: 202.927980 MHz, -51.956 dBm
Mkr 2: 204.640094 MHz, -55.630 dBm
Mkr 3: 206.349832 MHz, -54.140 dBm
Start 201.000000 MHz Center 204.500000 MHz Stop 208.000000 MHz
Span 7.000000 MHz 14735 pts in 562 ms

Center 204.500000 MHz
Span 7.000000 MHz
Start 201.000000 MHz
Stop 208.000000 MHz
Step 20.000000 MHz
Ref -30.000 dBm
Div 10.000 dB
Gain Auto Gain
Atten Auto Atten
Preamp Auto
Native RBW ☐
RBW 3.000000 kHz
VBW 1.000000 kHz
Auto RBW ✓

SA44B 41.50 C ~ 4.74 V Serial 32950440 Firmware Version 2.10

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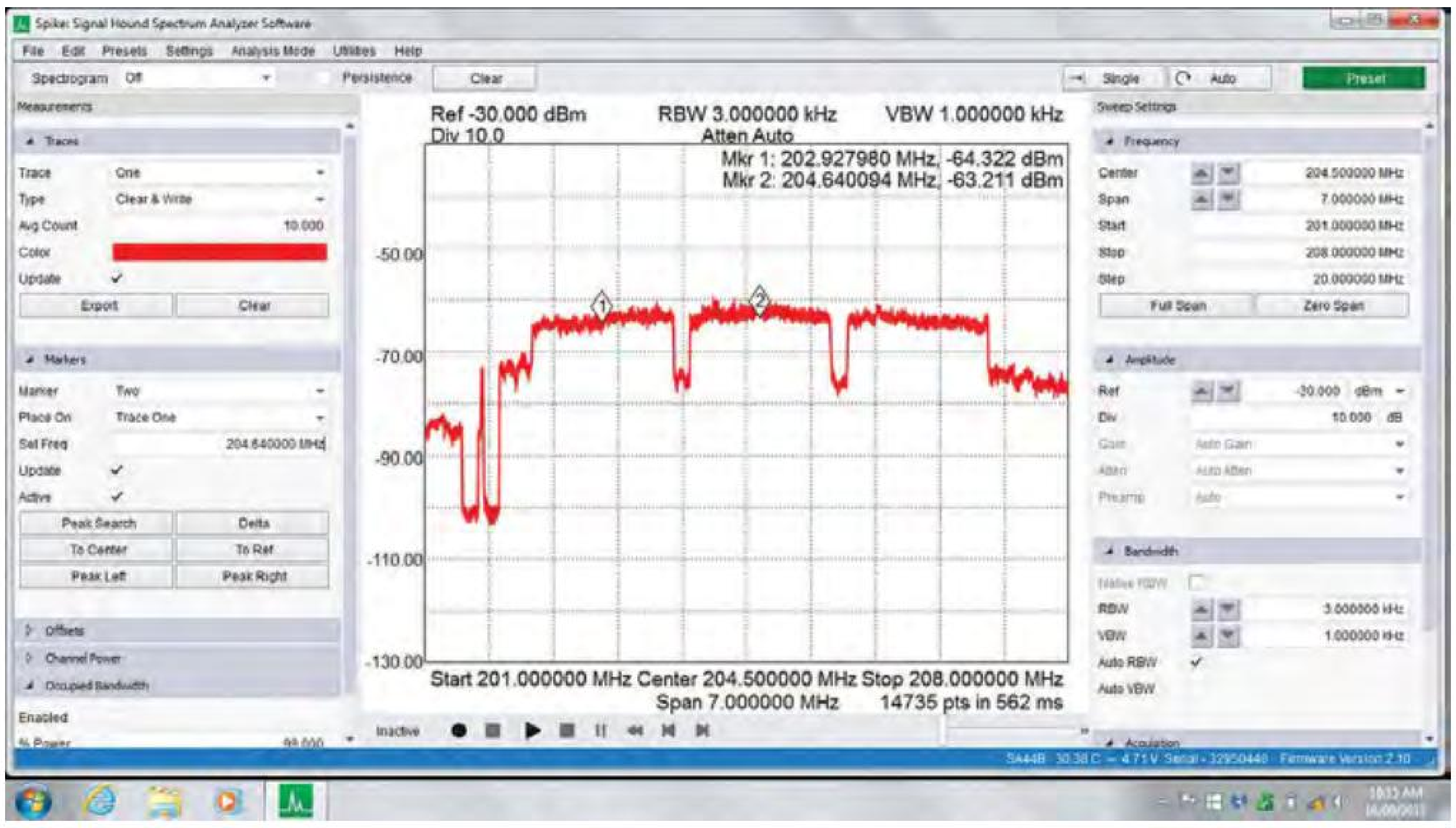
Zero Span
Amplitude
Bandwidth
Auto VBW
Acquisition
Inactive
-50.00
-70.00
-90.00
-110.00
-130.00
1
2
3

This 'waterfall' screen grab shows the signal picked up by the 5-element antenna from a location in Sydney's Arncliffe, aimed at the Redfern DAB transmitter (<5km away). It shows the signal levels of the three bands (9A, 9B and 9C). This measurement was taken by the Signal Hound USB Spectrum Analyser (from Silvertone Electronics [www.silvertone.com.au]).



Spike: Signal Hound Spectrum Analyzer Software

Spectrogram Off

Trace One
Type Clear & Write
Avg Count 10.000
Update ✓

Marker Two
Place On Trace One
Set Freq 204.640000 MHz
Update ✓
Active ✓

Ref -30.000 dBm RBW 3.000000 kHz VBW 1.000000 kHz
Div 10.0 Atten Auto
Mkr 1: 202.927980 MHz, -64.322 dBm
Mkr 2: 204.640094 MHz, -63.211 dBm
Start 201.000000 MHz Center 204.500000 MHz Stop 208.000000 MHz
Span 7.000000 MHz 14735 pts in 562 ms

Center 204.500000 MHz
Span 7.000000 MHz
Start 201.000000 MHz
Stop 208.000000 MHz
Step 20.000000 MHz
Ref -20.000 dBm
Div 10.000 dB
Gain Auto Gain
Atten Auto Atten
Preamp Auto
Native RBW ☐
RBW 3.000000 kHz
VBW 1.000000 kHz
Auto RBW ✓

SA44B 30.38 C ~ 4.71 V Serial 32950440 Firmware Version 2.10

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Zero Span
Amplitude
Bandwidth
Auto VBW
Acquisition
Inactive
-50.00
-70.00
-90.00
-110.00
-130.00
1
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By comparison, this Spectrum Analyser display was taken with a vertical whip antenna adjusted to 368mm long (1/4 wavelength) and with a substantial ground plane. As you can see, the received signal level is about 12dB less than that received with the 5-element Yagi described here.

Buying the alumimium

Aluminum is widely available, try **ebay.co.uk** or **www.metals4u.co.uk**

You might be able to purchase your aluminium from a nearby metal supplier and in that case, they might also cut it to the various lengths you will need (perhaps for a small extra charge?).

One drawback of buying tube from certain retailers is that every item you purchase may have an adhesive label attached, which is obviously meant to last for longer than the life of the product! At least, it seems that way when you are trying to remove seven labels – it took ages! At least I ended with highly polished tubes!

Screws and nuts

After a few years' exposure to the elements, many antennas are in a poor state. Aluminium may not 'rust' but it does oxidise, particularly in seaside areas or in metropolitan areas where there is a lot of industrial fallout.

Corrosion will also be a lot worse if you don't use the right screws and nuts. We strongly recommend the use of stainless steel screws, nuts and washers throughout, whether for machine screws or self-tappers. They do cost a little more but they last indefinitely. You will find a good array of stainless steel screws available from ships' chandlers.

Don't, on any account, use brass screws. When used to attach aluminium elements these will corrode away almost before your eyes. Nor do we recommend galvanised, bright zinc or cadmium-plated steel screws.

In seaside areas these can be visibly corroded with just a few days' exposure.

In rural areas, away from the sea or city pollution, you can probably get away with galvanised screws, but the antenna will last longer if you paint it.

Starting work

Constructing this antenna is quite straightforward. If you have all the materials available you can probably do it in a couple of afternoons.

Fig.1 shows all the details of the 5-element antenna. It shows the dimensions of all the elements and the various hardware bits you will have to make to assemble the antenna. At top is a plan view showing the length of all five elements and their spacing along the boom.

Before you start, make sure you have all the aluminium and hardware listed in the Parts List. You will be frustrated if you get half-way through and find you can't progress further because you lack screws or some other item. Get 'em all before you start!

You need to cut the 19mm square tube (the boom) to length and then mark it for drilling and this is where it is quite easy to make mistakes.

If you are experienced in metalwork and have access to a set of vee-blocks

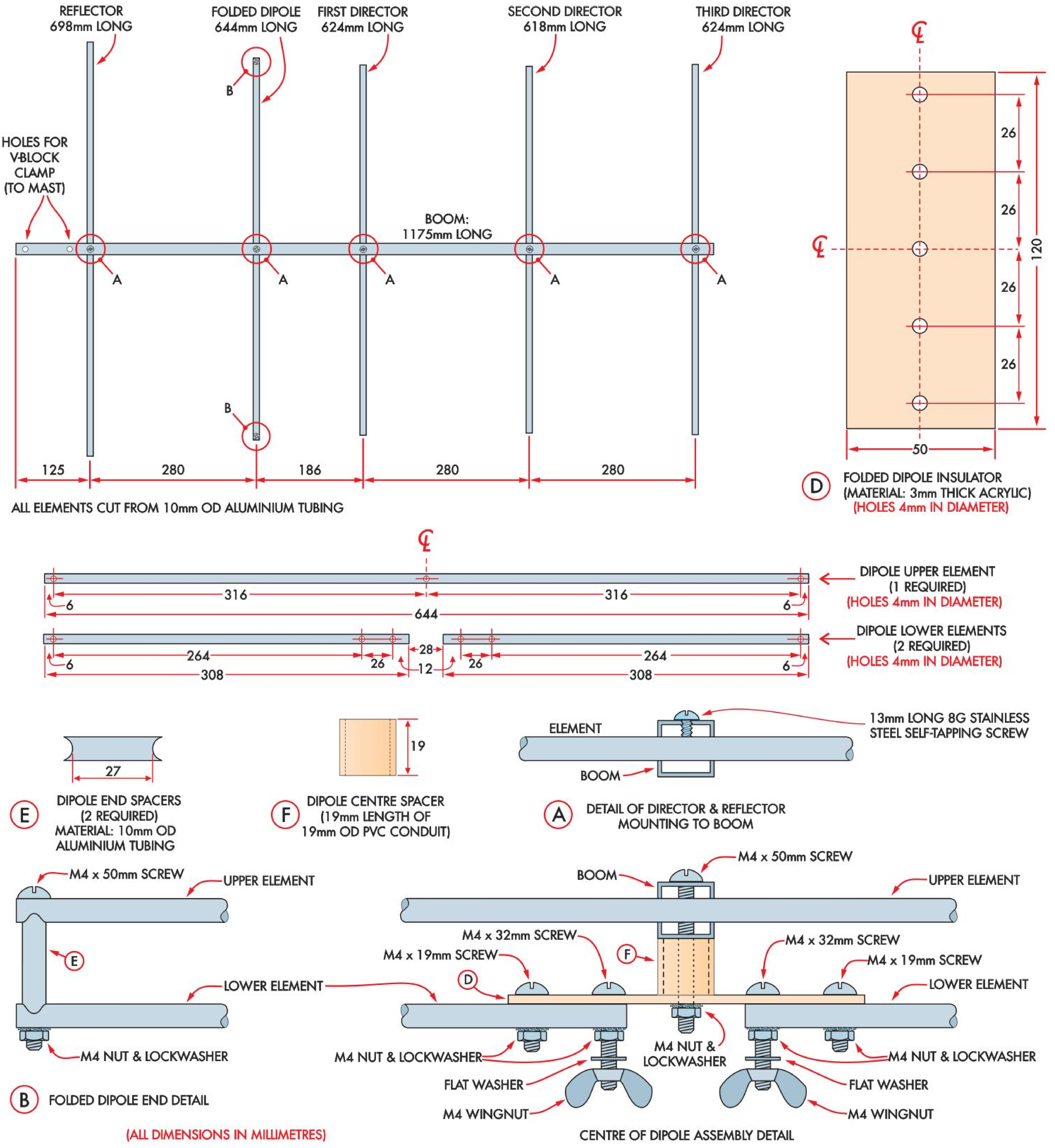
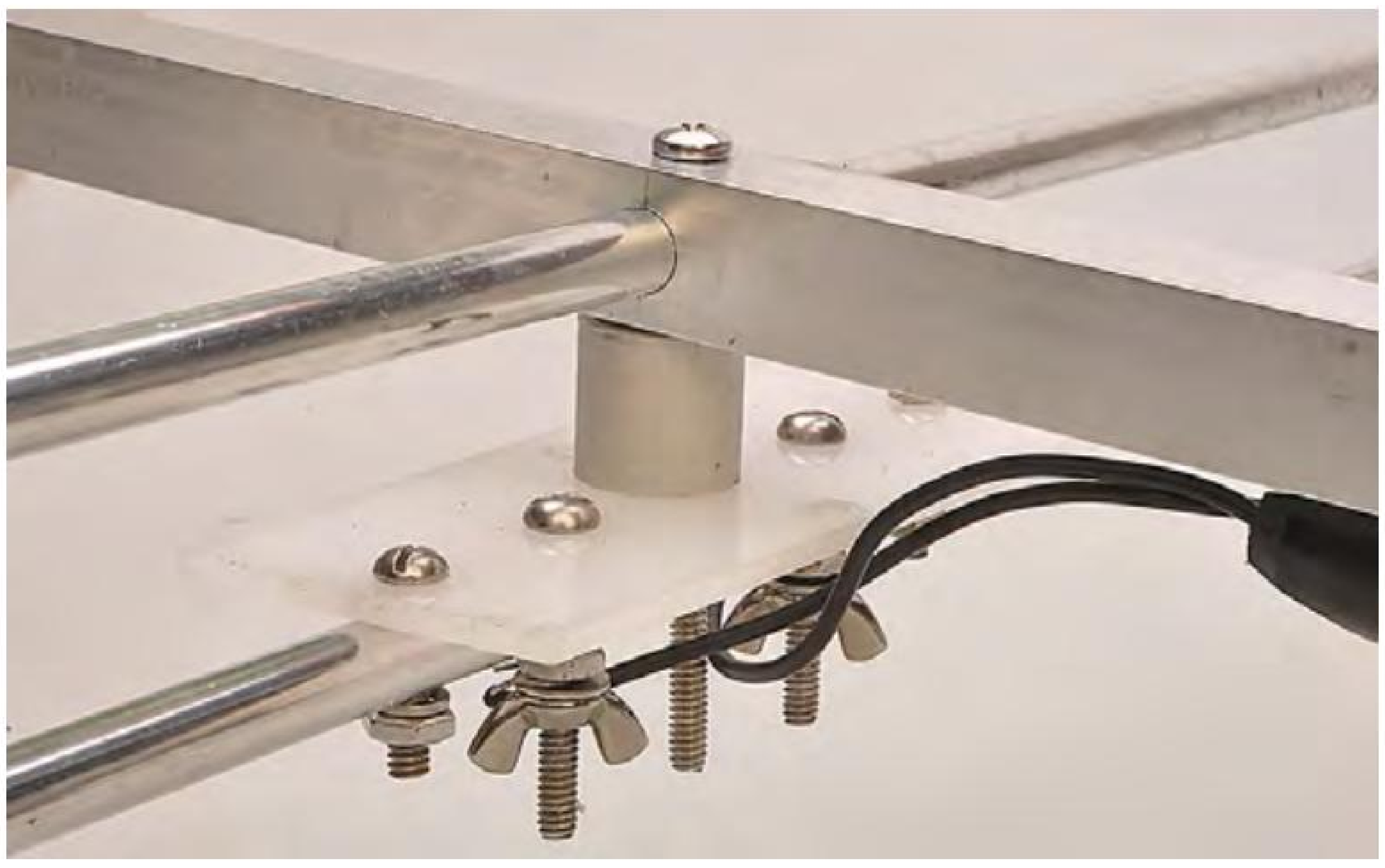
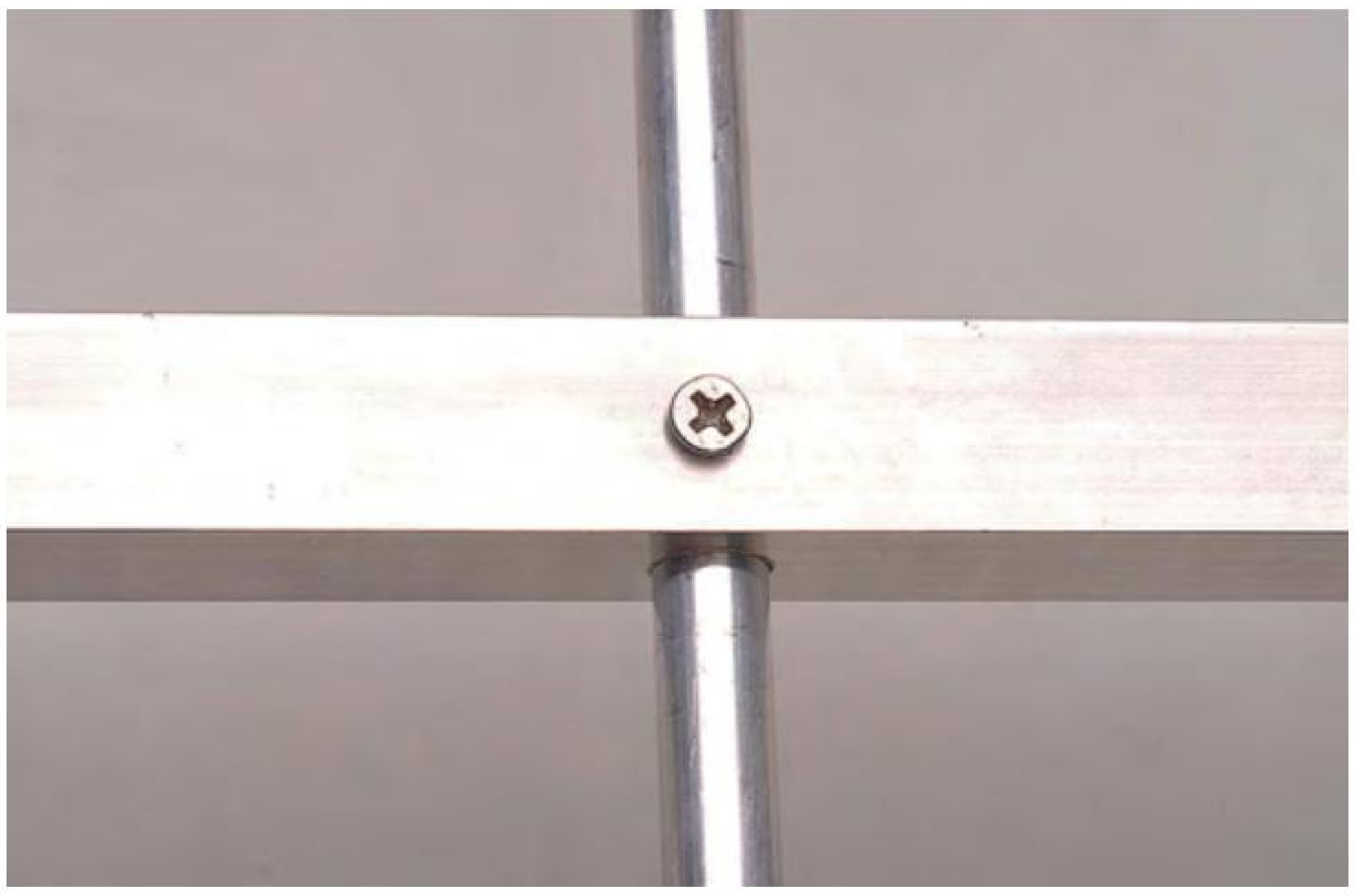

REFLECTOR 698mm LONG
FOLDED DIPOLE 644mm LONG
FIRST DIRECTOR 624mm LONG
SECOND DIRECTOR 618mm LONG
THIRD DIRECTOR 624mm LONG
HOLES FOR V-BLOCK CLAMP (TO MAST)
BOOM: 1175mm LONG
A
B
125
280
186
280
280
ALL ELEMENTS CUT FROM 10mm OD ALUMINIUM TUBING
℄
26
26
26
26
120
50
D
FOLDED DIPOLE INSULATOR (MATERIAL: 3mm THICK ACRYLIC)
(HOLES 4mm IN DIAMETER)
316
316
6
644
DIPOLE UPPER ELEMENT (1 REQUIRED)
(HOLES 4mm IN DIAMETER)
264
26
28
12
308
DIPOLE LOWER ELEMENTS (2 REQUIRED)
(HOLES 4mm IN DIAMETER)
27
E
DIPOLE END SPACERS (2 REQUIRED) MATERIAL: 10mm OD ALUMINIUM TUBING
19
F
DIPOLE CENTRE SPACER (19mm LENGTH OF 19mm OD PVC CONDUIT)
ELEMENT
BOOM
13mm LONG 8G STAINLESS STEEL SELF-TAPPING SCREW
A
DETAIL OF DIRECTOR & REFLECTOR MOUNTING TO BOOM
M4 x 50mm SCREW
UPPER ELEMENT
LOWER ELEMENT
M4 NUT & LOCKWASHER
B
FOLDED DIPOLE END DETAIL
M4 x 32mm SCREW
M4 x 19mm SCREW
FLAT WASHER
M4 WINGNUT
CENTRE OF DIPOLE ASSEMBLY DETAIL
(ALL DIMENSIONS IN MILLIMETRES)

Fig.1: this diagram shows all the details of the 5-element antenna. At top is a plan view, while the other diagrams show hardware and element mounting details.



This topside view of the antenna shows how the folded dipole is attached to the square boom. Note the short section of PVC conduit which acts as a spacer between the underside of the boom and the dipole insulator plate. Whitworth or other machine screws hold it all together.



The reflector and director elements are attached to the boom using self-tapping screws. Ideally, all screws, nuts and washers should be stainless steel to avoid corrosion. To check that screws are stainless, take a magnet with you when buying them. If they attract, they ain't stainless!

and a drill press, you could substitute 25mm diameter tubing for the boom. In fact, you could use 25mm stainless steel round tubing which is readily available from plumbing supply stores, but it is expensive and not easy to work.

Centre-punch the boom for all holes prior to drilling. The boom is 1250mm long and the total of the element spacings along the boom is 1100mm – see the plan diagram on Fig.1. Mark the hole centre position for the reflector element first, 125mm from one end of the boom, and then work your way along.

If you have a drill press that lets you drill all the element holes square through the boom you are fortunate. If not, mark the hole centre positions on both sides of the boom and drill from both sides. If you don't get the element holes lined up properly, you will have the elements skew-whiff.

A few words of advice on drilling is appropriate here. Drilling in thin wall aluminium tubing can be a problem and many people tend to end up with holes that are more triangular than round. The way around this problem is to drill all the large holes (ie, all 10mm holes) under size and then ream them out to the correct size using a tapered reamer.

Don't drill the larger diameters with too high a speed otherwise there may be a tendency to produce 'triangular' holes.

If you have a bench drill which allows you to set slower drilling speeds, so much the better. Either way, it is best to drill the element holes to 10mm and then slightly increase each hole with a tapered reamer so that each element is held firmly in the boom.

Reaming larger holes

Be careful when reaming holes out though because it is quite easy to get carried away and then end up with holes that are oversize. Use a scrap piece of 10mm tubing to test when the holes specified at 10mm are the correct size.

Each director element and the reflector is held in the boom with a self-tapping screw, as shown in diagram A of Fig.1. Drill a 3mm hole at the centre point of each element, but only through one side. Don't mount the elements on the boom yet though because the dipole should be assembled and mounted on the boom first.

You need to keep a mental image of how the finished antenna will appear. All the directors, the folded dipole and the reflector will all be vertical (ie, perpendicular) but the holes for the clamp, at the reflector end of the boom, will be horizontal.

Confused? Take another look at the photos of the finished antenna.

Now cut the 10mm diameter tubing for the director, three reflectors and parts for the dipole. Remember the old adage about 'measure twice and cut once'. It's hard to lengthen elements that are too short. Note that two of the directors are the same length, ie, 670mm, while the other is 664mm.

Making the dipole

The folded dipole is made from five pieces of 10mm aluminium tubing, three long and two short. The detail of its assembly can be seen from the diagram at the bottom of Fig.1. The two short tubes, shown as diagram E on Fig.1, are cut and shaped so that they key in with the top and bottom elements of the dipole. Further detail is shown in the accompanying photos.

The top and bottom pieces of the dipole are held at each end with a 60mm-long M4 screw (or 3/16-inch Whitworth), together with a nut and lock washer. At the centre, the lower halves of the dipole are terminated on an insulating plate (shown in diagram D of Fig.1). This plate is made of 3mm acrylic (Perspex or Lexan). The dipole halves are each secured to the insulating plate with a 19mm-long M4 (or 3/16-inch Whitworth) screw, nut and lock-washer.

Terminals for the dipole are provided with two 32mm-long M4 or 3/16-inch Whitworth screws, each fitted with a nut and lock-washer plus a wing nut and flat washer.

The insulating plate is secured to, and spaced off the main boom via a 19mm length of 19mm PVC conduit, shown as a 'folded dipole spacer' in diagram F of Fig.1.

The top piece of the dipole is secured to the boom with a 60mm-long 3/16-inch Whitworth or M4 screw, nut and lock-washer

The details of the dipole insulating plate and fixing to the boom can be seen in the accompanying photos. Note that while we used white Perspex, you could use a piece of polycarbonate if that is what you have on hand. However, note our remarks on painting, later in this article.

The antenna now looks near complete. You need to add the antenna clamp, to enable it to be attached to the mast. This *must* be mounted at the end of the boom (ie, behind the reflector) and oriented to allow the elements to sit vertically.

You will also need a 300Ω-to-75Ω balun to match it to 75Ω coax cable. You *could* use 300Ω ribbon if you wish and omit the balun, but to obtain the most interference-free signal, we recommend coax cable for your installation.

Unfortunately, many antenna clamps are sold with a cadmium-plated and passivated finish (which look like a 'gold' finish). This is barely adequate for inland areas but rusts quickly in sea air. We may seem to be paranoid about corrosion but since my office is only a kilometre or so from the seaside I'm very aware of just how quickly metal hardware can rust and corrode.

If you can, buy U-bolts and clamps that are stainless steel, as used for car exhaust systems (or boat fittings), as these will last a lot longer. At minimum, choose hot-dip galvanised.

Be aware that zinc 'plated' fittings are not as rust resistant as galvanised types. Zinc-plated fittings have a smooth bright appearance while hot-dip galvanising is unmistakable – it has quite a rough appearance.

We also suggest that the ends of all the elements and the boom be stopped up with silicone sealant. This will stop them from whistling in the wind. (Commercial antenna manufacturers tend to squash the ends flat for this purpose).

Better still, you can buy Delrin plugs to suit the square aluminium tubing, which also look neater.

If you live in an area where corrosion is a problem, it is also a good idea to paint your antenna. If nothing else, the dipole insulating plate should be painted as acrylic material does deteriorate in sunlight (ie, UV).

We suggest you leave the antenna for a month or so to weather it and then paint it with an etch primer. Finish it with an aluminium-loaded paint.

Installation

When you have finished your antenna you need to carefully consider its installation. There is no point in going to a lot of trouble making it if you don't install it properly.

Try to install your new antenna well away from existing TV antennas as these can have quite a serious effect on the performance.

Similarly, nearby metal guttering, electric cabling, metal roofing or sarking (ie, reflective insulation such as Sisalation) can have a bad effect on antenna performance. And don't forget the effect of a water tank which may be lurking just beneath the roof tiles.

If you live on a busy street, try to install your antenna as far away as possible from the traffic side of your house. That will help minimise ignition noise from passing traffic.

Finally, install the antenna as high as possible above the roof and guttering. If that is a problem, try to install the antenna so that it is at least a half wavelength away from the nearest metallic object such as guttering or roofing. This means a distance of about 750mm away from guttering.

Take care when installing the antenna. Safe working with ladders is particularly important. Take your time and don't take risks. You don't want to end up listening to hospital radio!

Line up the antenna so that it is aimed at the closest DAB transmitter, or the one that gives you best performance (eg, minimal errors shown on the DAB station readout). More often than not, they will be the same transmitter.

Choosing coax cable

You probably know that there is a wide range of prices for coaxial cable, ranging from pence to pounds per metre. What's the difference and why is it important? When it comes to coax quality, price is usually a pretty good guide.

Apart from the coax impedance (you want 75Ω), the main criteria you look for is attenuation, or loss. Unfortunately, all coax is lossy – this means that even if you get the last microvolt of signal from your antenna, depending on the quality of the coax lead, some of it/a lot of it/most of it can be lost on the trip to your receiver.

As a matter of interest, when we were checking out the performance of this antenna, we were getting diabolically bad results. It turned out that the length of coax cable was bad – really bad! Swapping to a new length of cable gave the results we were expecting.

Cheaper coax has a solid plastic dielectric, mid-range has an extruded pattern which is mostly air (hence 'air-core'); the best domestic coax has 'foam core' dielectric, (which has minimum loss) and the outer conductor is not only pretty tightly woven (for minimum loss) it also has one or more levels of aluminium foil surrounding the copper mesh (for minimum loss AND to minimise interference!)

Attenuation is expressed in dB/100m and increases as frequency increases. Because we're not talking super high frequencies (~200MHz) you can be a bit less fussy in selecting coax.

If you're making this antenna because you need all the signal you can get to avoid the 'digital cliff' – and especially if the length of coax lead-in needs to be relatively long – buy the best coax you can afford, within reason.

When the antenna is mounted on its mast, make sure the coax is firmly secured to that mast (and to the antenna boom) with cable ties, otherwise the cable can flap around in the wind.

There is nothing more annoying than lying in bed late at night and listening to the cable slapping against the mast – cable ties are cheap, so use them!

Performance

Before conducting any measurements, we hooked the Yagi up to a 'generic'

Parts List – DAB Antenna

Aluminium (see text)

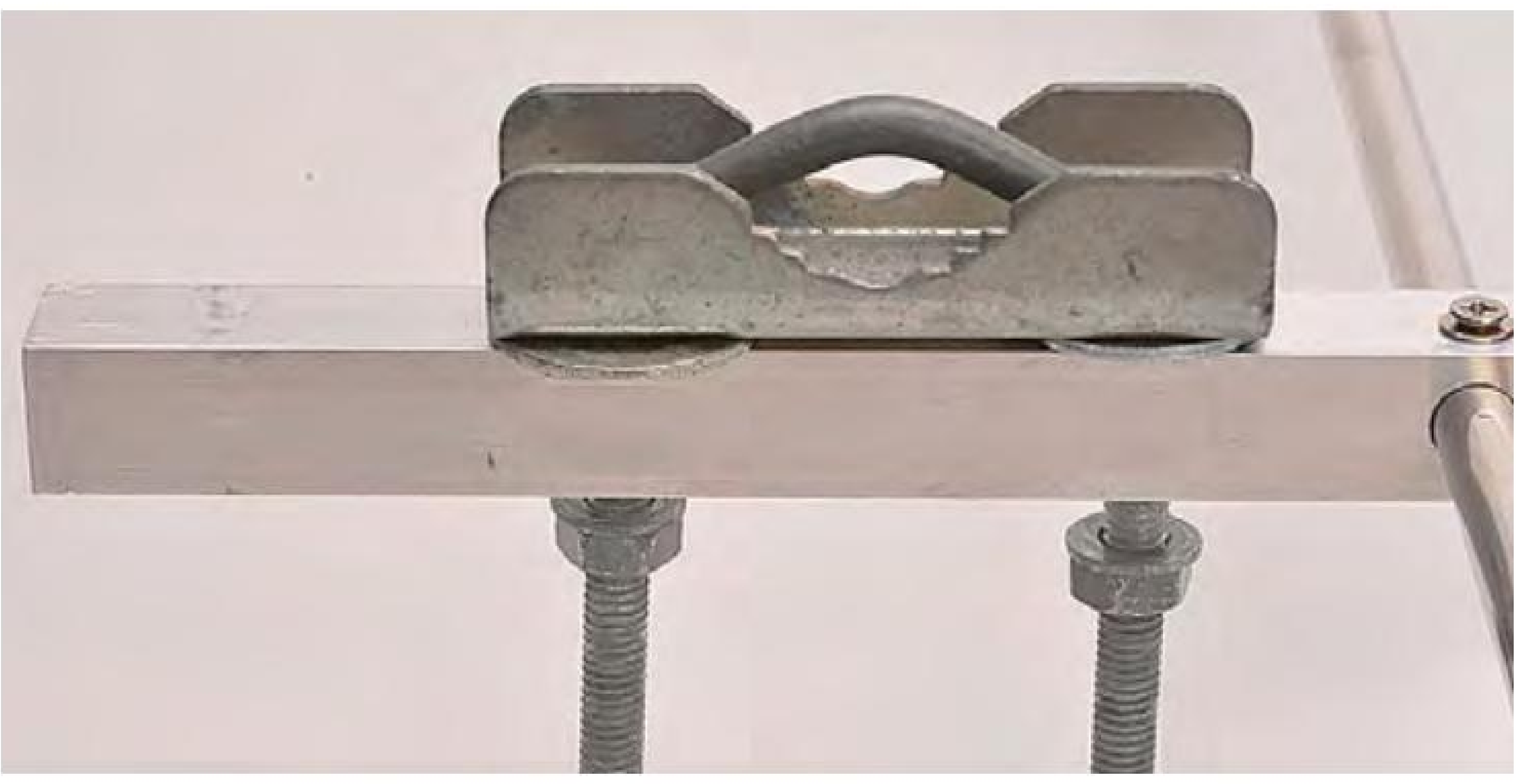
1.25 metres of 19mm square tubing with 1.2mm wall thickness
4.5 metres of 10mm diameter tubing with 1mm wall thickness

Hardware

1 120 × 40 × 3mm white perspex
1 stainless steel or galvanised U-bolt and V-clamp to suit mast
4 8G × 13mm self-tapping screws
3 M4 × 60mm or 3/16in Whitworth screw (round head)
2 M4 × 32mm or 3/16in Whitworth screws (round head)
2 M4 × 19mm or 3/16in Whitworth screws (round head)
7 M4 or 3/16in nuts
2 M4 or 3/16in wing nuts
7 M4 or 3/16in lock washers
2 M4 or 3/16in flat washers
Note: all screws, washers and nuts should be AS316-grade stainless steel
1 19mm long spacer cut from 19mm conduit or similar

Miscellaneous (sizes/lengths to suit)

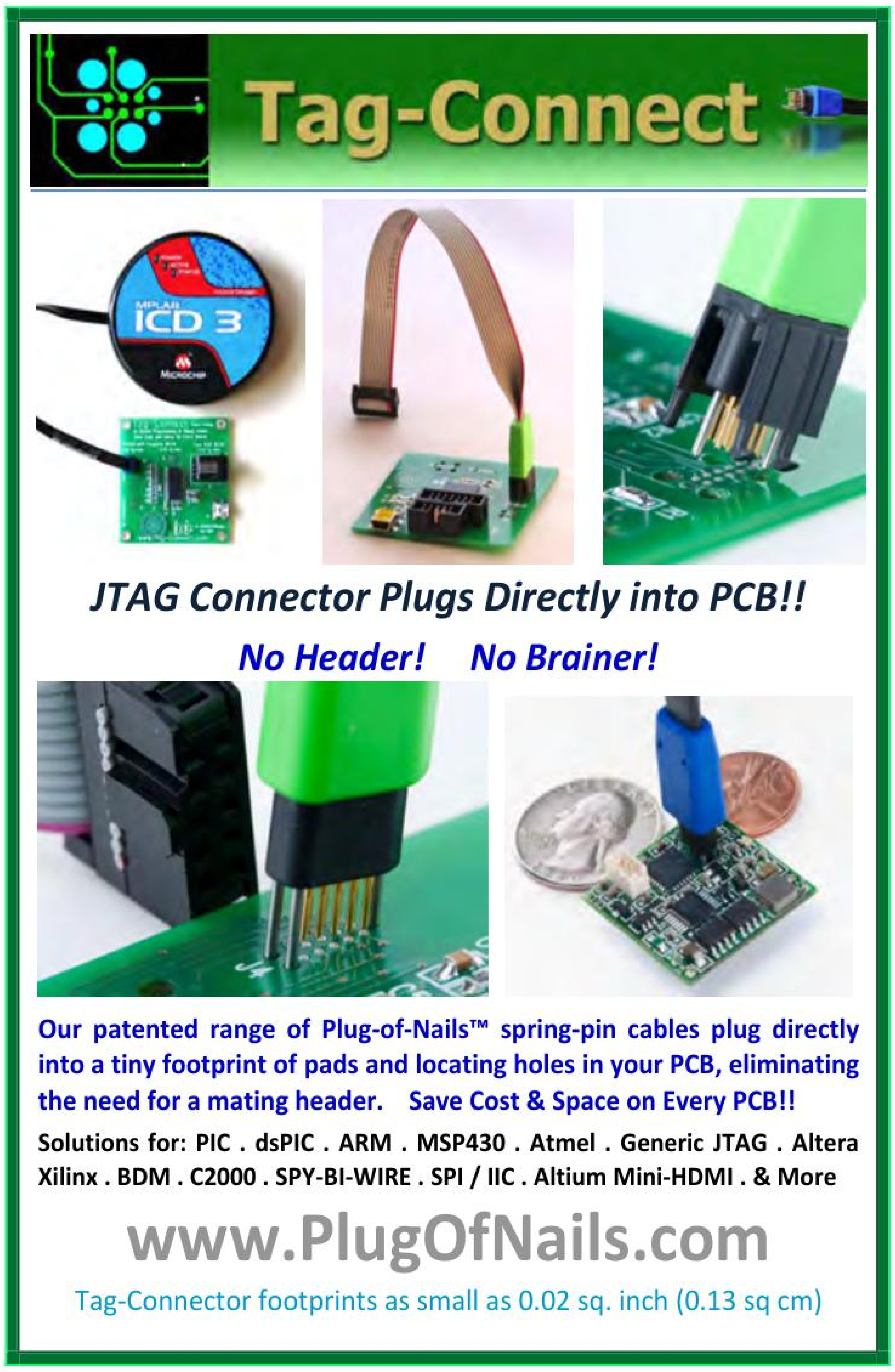
Mast and wall mounts or barge-board mount (hockey stick style)
300Ω-to-75Ω in-line balun (Jaycar Cat LT-3028 plus matching F-connector)
Quality 75Ω coax cable (Jaycar WB-2006/9, Hills SSC32 or equivalent)
Plastic cable ties
Silicone sealant



The V-block/U-bolt clamp should ideally be stainless steel or at worst, hot-dip galvanised (don't use Cadmium-plated [or 'passivated'] steel – they rust before your eyes!). It must mount between the reflector (seen here on the right) and the end of the boom, so that the mast doesn't interfere too much with the signal. Note the orientation – it mounts so that the elements are vertical when the clamp is attached to the mast.

DAB radio in a known poor-signal area. What a difference! The Yagi pulled in quite a few stations which were simply not there before; of those that were, signal levels were much improved.

Then, to prove the performance of the DAB Yagi, we took a number of spectra using a Signal Hound Spectrum Analyser. Two of these graphs are shown on page 34 – they confirmed our first tests and demonstrate that the new antenna has a gain of around 12dB with respect to a whip antenna – that's pretty good and well worth the investment!



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Connecting your DAB Antenna

OK, so you've finished your DAB Yagi and now you're ready to connect it to your receiver. Most DAB tuners do have an antenna input socket, so that makes it easy.

But the vast majority of DAB radios (especially the smaller ones and virtually all portables) are not equipped with any form of antenna input, apart from the whip antenna. So how can you connect an external antenna?

What are the connection options?

The antenna (and the coax lead in) require a connection to both the antenna input and earth. And with very few exceptions, there is nowhere on the outside of the case to get an earth connection.

So you need to install a socket on the back of the receiver which the cable from the antenna could be plugged into.

Fitting a socket

Open up your receiver and find an appropriate place to mount a socket. While the back panel of our receiver is quite spartan; inside, the possible locations are limited by existing fittings and hardware. Two main points to watch when choosing a location are:

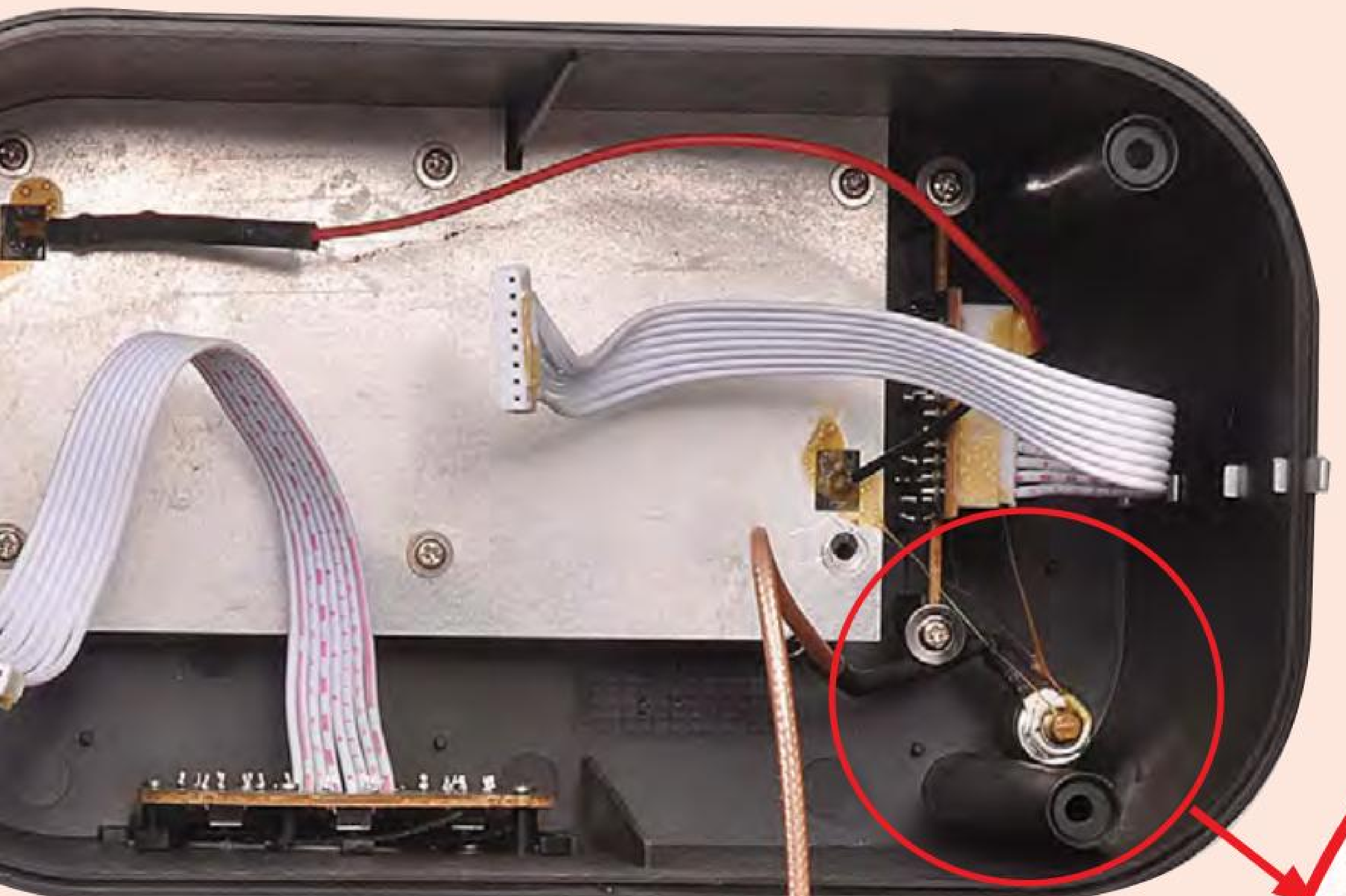
a) Mount it as close to the receiver's input terminals as possible to keep your input wires as short as possible (we are using ordinary hookup wire, not coax)
b) Check inside the receiver to make sure the mounting position will not foul any internal hardware – and that you have enough room to fit any washers/nuts to hold the sockets in place.

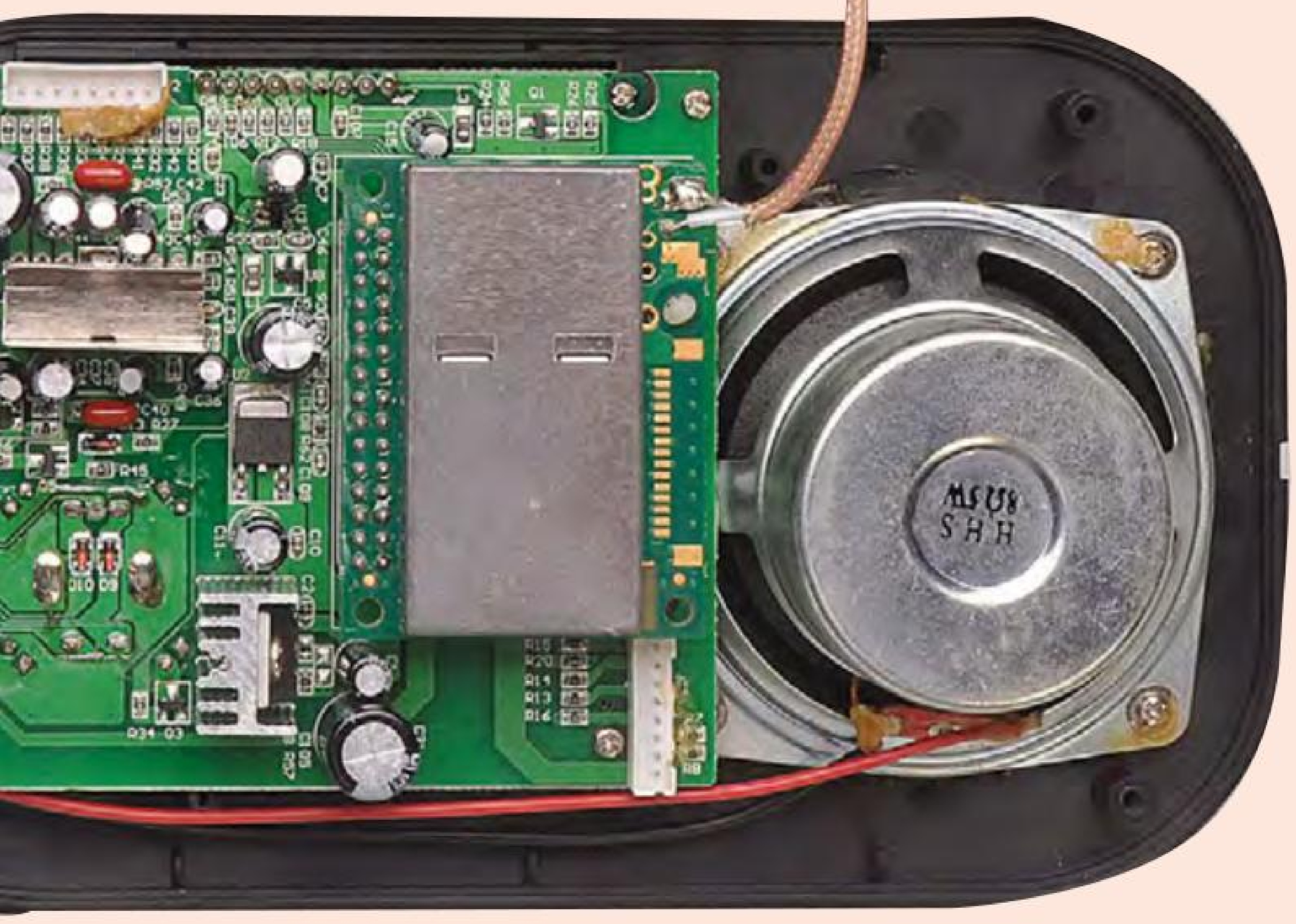
The type of socket is up to you – those receivers which do have input sockets often use standard 3.5mm 'audio' types because they're nice and small. However, we elected to use a standard 'Belling Lee' socket (sometimes called a 'PAL' socket) as used on TV antennas, mainly because it seemed appropriate to use the 'normal' plug/socket for 75Ω coax.

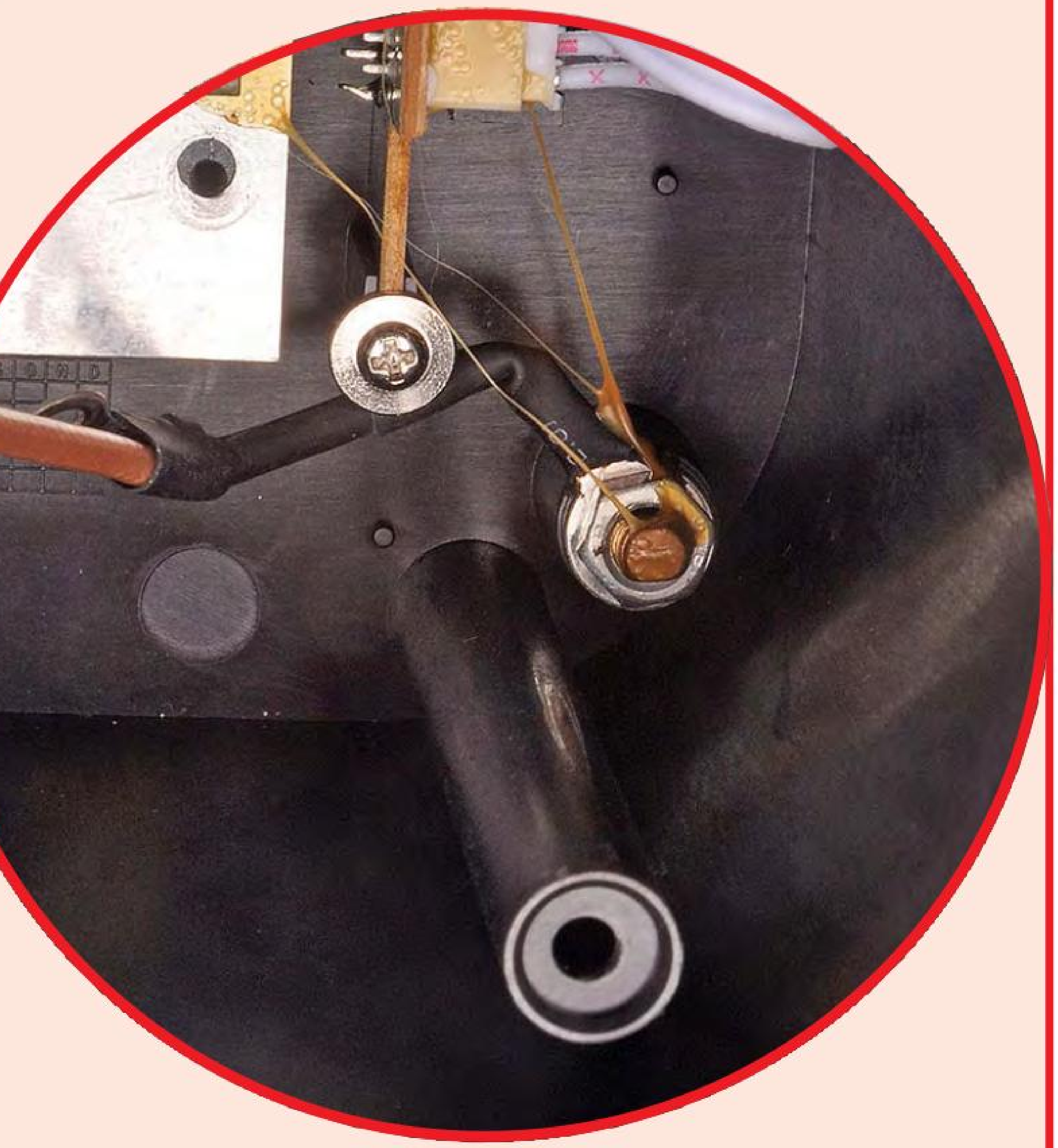
Fit the socket first, then wire the connections to the receiver. We chose to connect to the bottom end of the whip antenna mounting rather than the receiver's PCB because it was the shorter connection; the 'braid' connection from the socket connected to a solder lug under the same self-tapping screw which connected the receiver's ground plane.

We couldn't find a solder lug large enough to fit under the antenna mounting, so effectively made one by winding a double loop of hookup wire about 7mm in diameter and applying solder to that, making it rigid. We were fortunate when we removed the nut holding the whip antenna in place, there was plenty of 'meat' left on the thread to allow our 'solder lug' to fit on as well. Our photographs explain all this in detail.

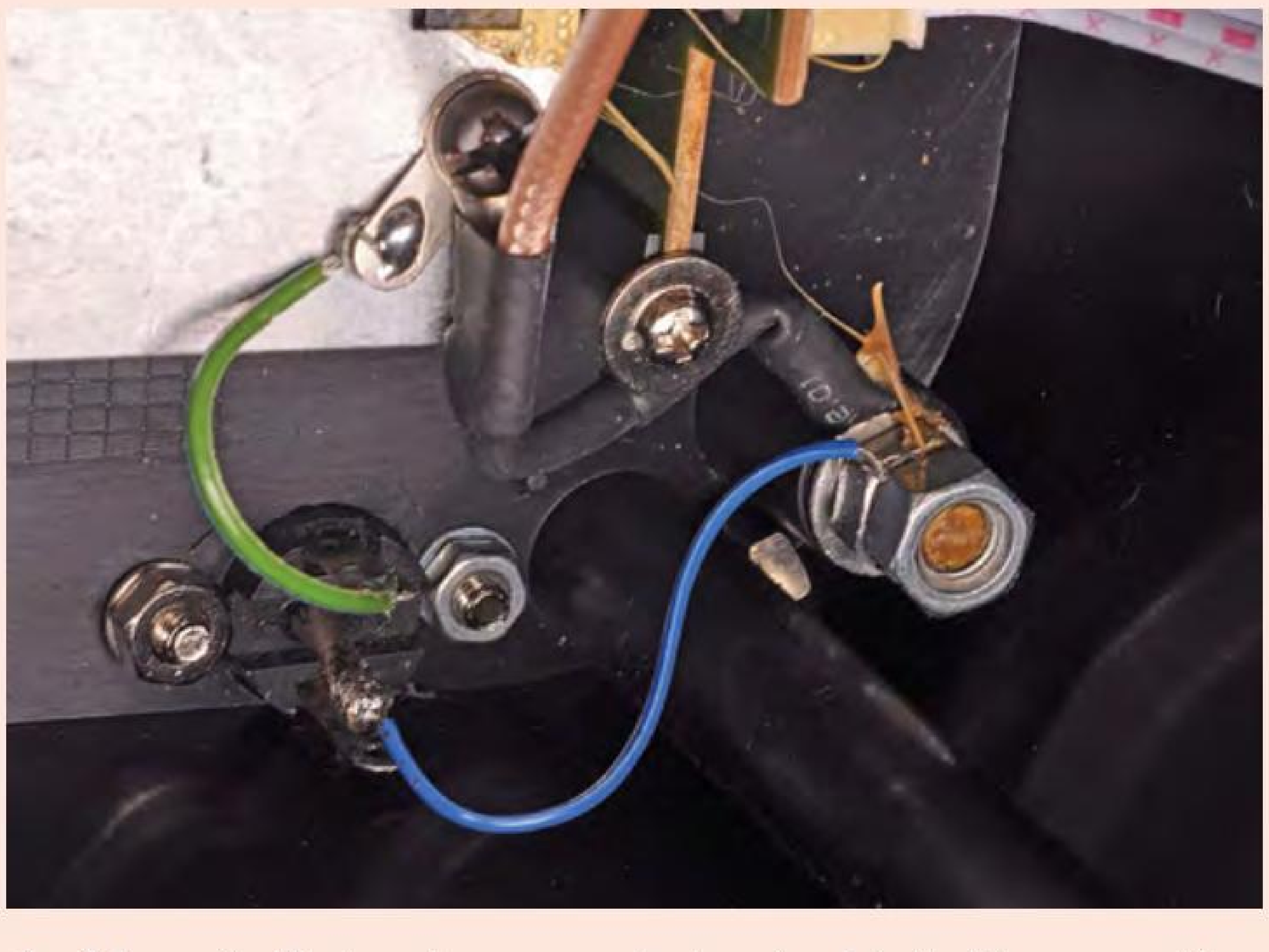
to your DAB Receiver



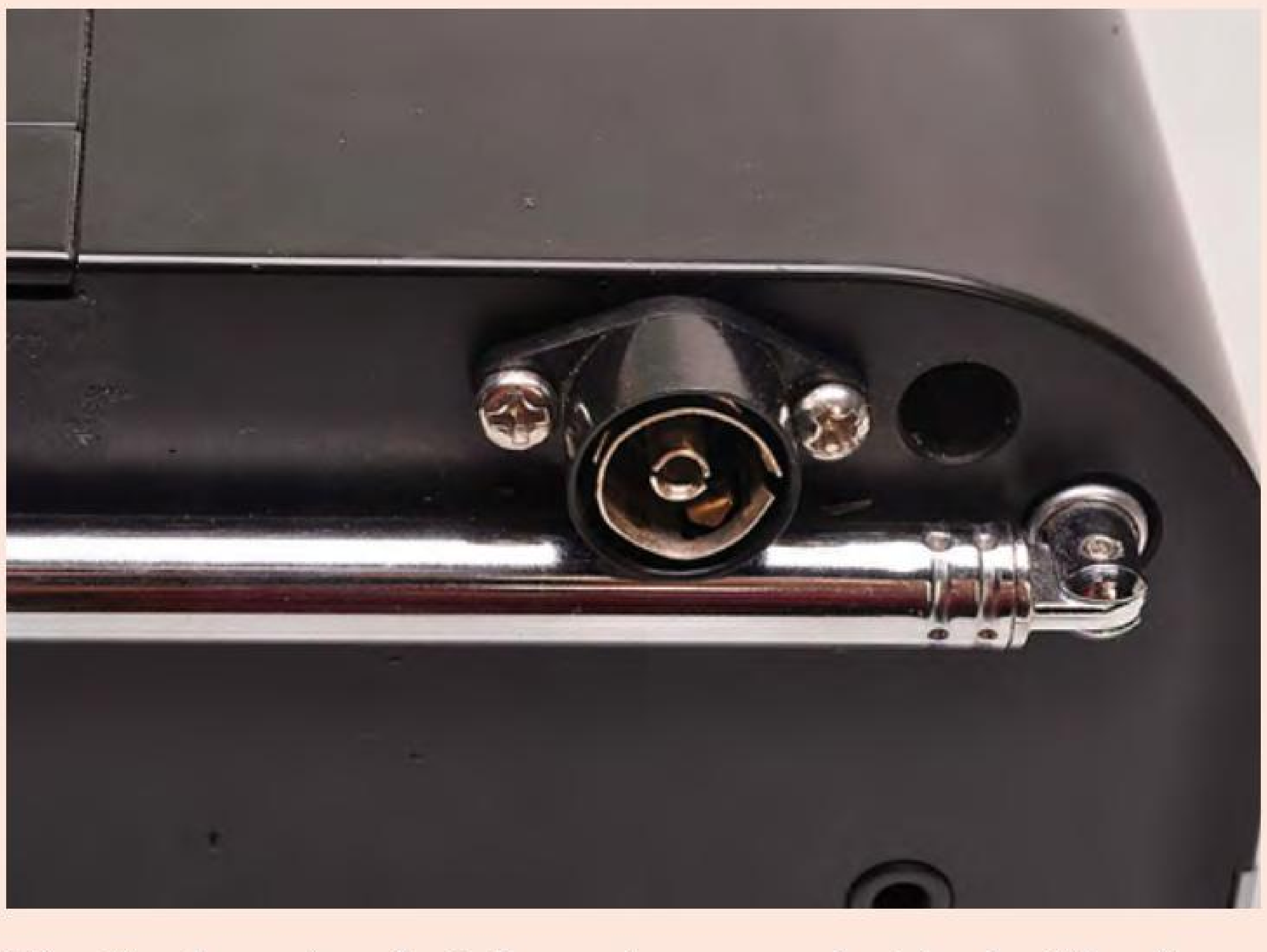




Opening just about any DAB receiver will reveal a PCB containing the DAB receiver module (the silver box middle of lower pic) with whip antenna connections close by. We elected to attach our external socket to the other end of the antenna cable because it was simpler. The photo below shows an enlargement of the area where we located the antenna socket. Be careful that you allow enough room for the socket and for its mounting screws – ours will end up very close to that vertical pillar.



And here is that antenna socket, wired into the mounting hardware for the whip antenna (the blue wire) and to a solder lug connecting to the ground plane and the antenna wire braid (green wire). We used ordinary hookup wire to make the connections.



Finally, here is what the antenna socket looks like from the outside. We used a standard Belling-Lee connector, just as you would find used on the antenna socket on most TV sets. A matching plug was wired to the end of the coax cable coming from the new DAB Antenna.

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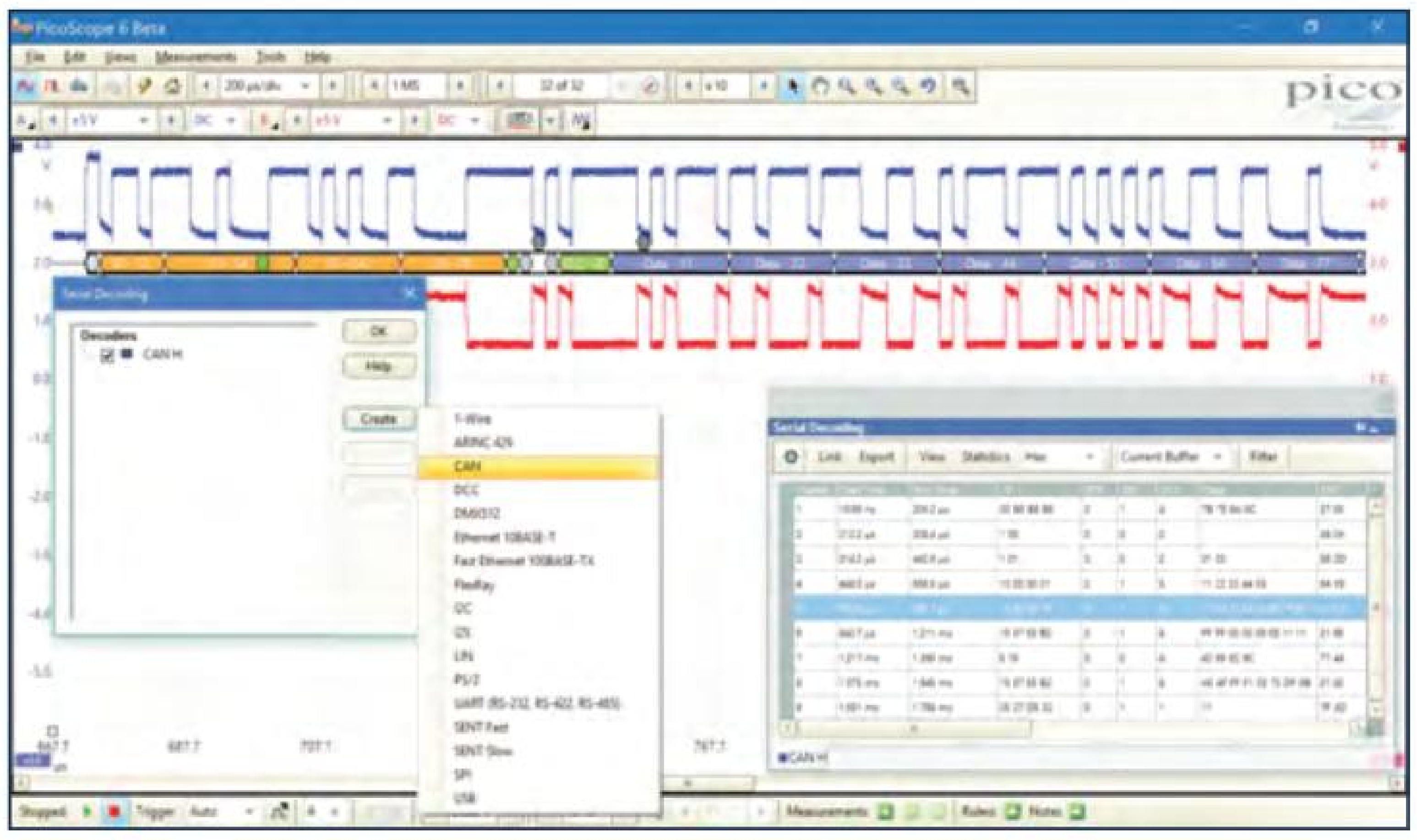

Two-channel, four-channel and mixed-signal models have the functionality of an oscilloscope plus a Logic Analyzer (on MSO models), Spectrum Analyzer, Function Generator, Arbitrary Waveform Generator and Serial Bus Analyzer with support for 16 protocols included as standard.

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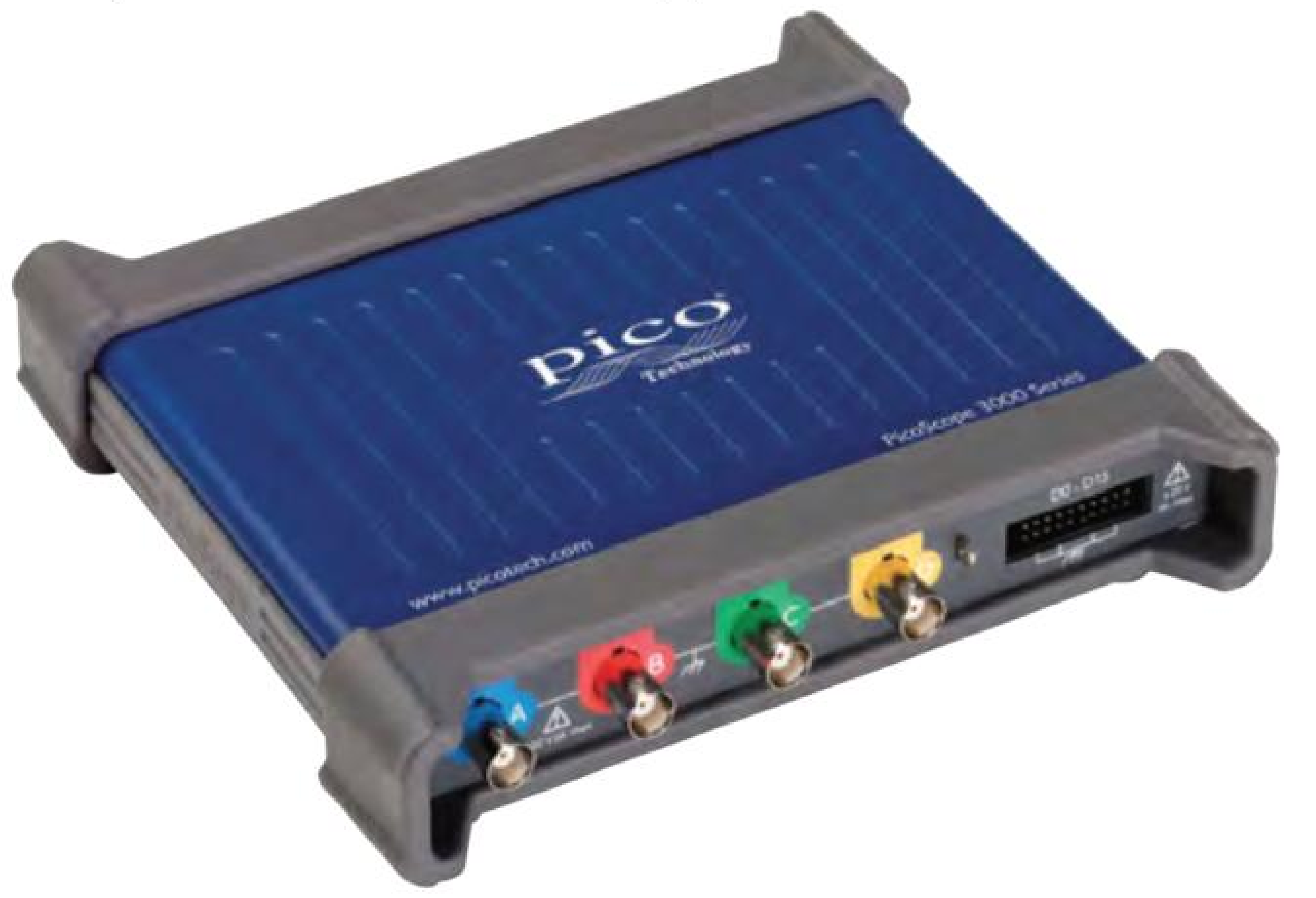

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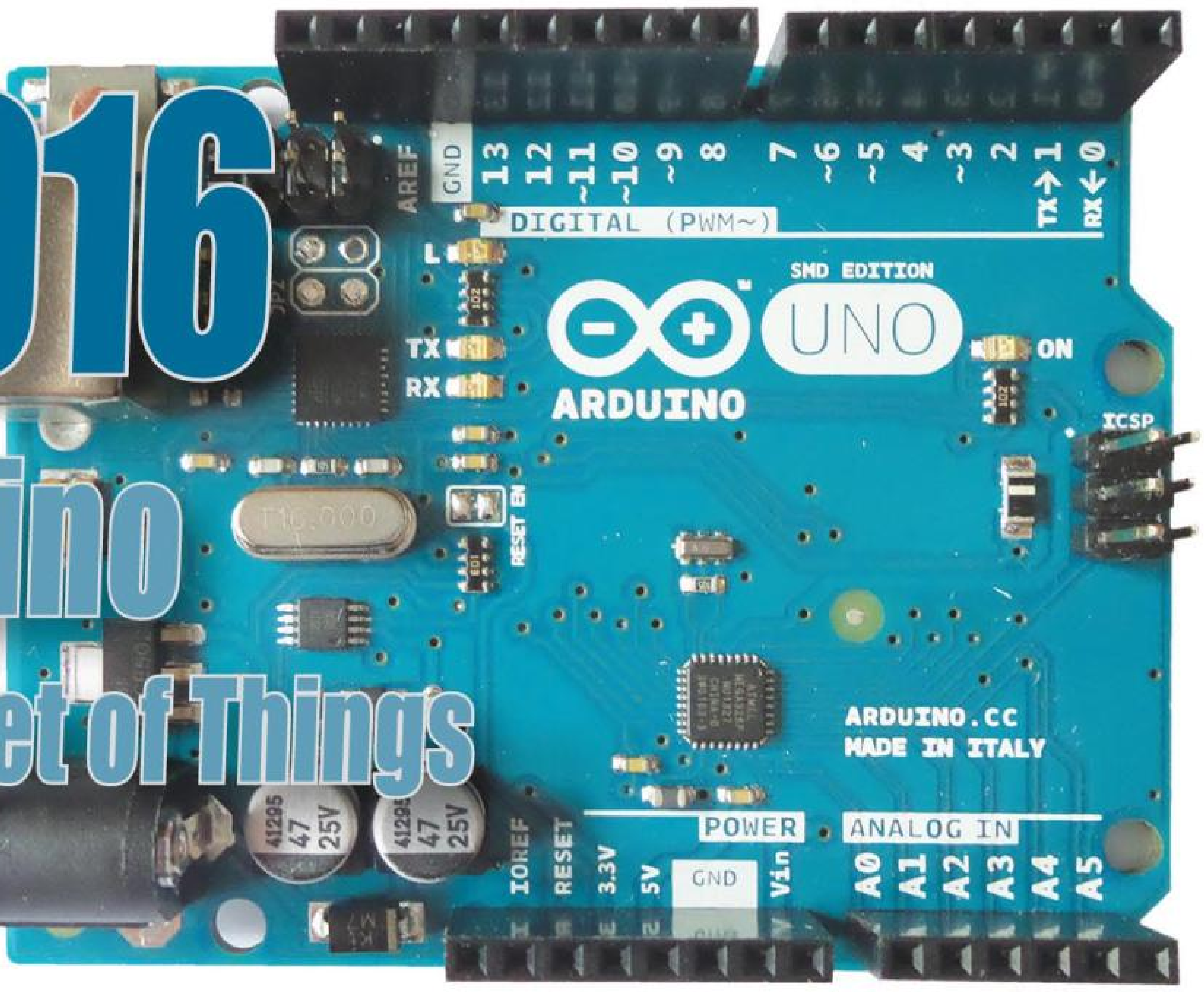
Teach-In 2016

Exploring the Arduino

Part 12: Wi-Fi and the Internet of Things



by Mike and Richard Tooley

Welcome Welcome to *Teach-In 2016: Exploring the Arduino*. This exciting new series has been designed for electronics enthusiasts wanting to get to grips with the immensely popular Arduino microcontroller, as well as coding enthusiasts who want to explore hardware and interfacing. So, whether you are considering what to do with your Arduino, or maybe have an idea for a project but don't know how to turn it into reality, our new *Teach-In 2016* series will provide you with a one-stop source of ideas and practical information.

In last month's *Teach-In 2016, Arduino World* looked at GPS modules for use with the Arduino. *Arduino Workshop* introduced you to the practical aspects of using GPS, and our programming feature, *Coding Quickstart* showed you how to use the Arduino's powerful TinyGPS library. Our *Get Real* project last month was devoted to the design and construction of a GPS location fixer that allowed you to accurately display the device's longitude and latitude.

This month

In this month's *Teach-In 2016, Arduino World* will take a look at wireless networking and the ESPDuino microcontroller that neatly combines Arduino compatibility with an ability to connect to a wireless network via an on-board ESP8266 wireless module. *Arduino Workshop* introduces you to the extended I/O facilities offered by the Arduino Mega, and our programming feature, *Coding Quickstart* will show you how to install and configure the ESPDuino's integrated development environment (IDE). Our *Get Real* project brings this *Teach-In 2016* series to a conclusion by showing you how to get started with the Internet of Things (IoT).

Arduino World: Wireless modules

One feature made glaringly obvious by its absence from many Arduino versions, such as the Nano and Uno, is the lack of built-in wireless connectivity. The 'official' solution, at least for the Uno, was that of adding a rather expensive Wi-Fi shield, but these are now classed as 'retired' and are no longer available. More recently, a new Wi-Fi development version of the Uno has been introduced but, while this neatly solves the problem of Wi-Fi connectivity, it is still a rather expensive solution. Not surprisingly, several Far East manufacturers have moved to fill the gap with add-ons featuring the popular, powerful and inexpensive family of ESP8266 serial-controlled Wi-Fi gateway modules manufactured by the Chinese company, Espressif Systems.

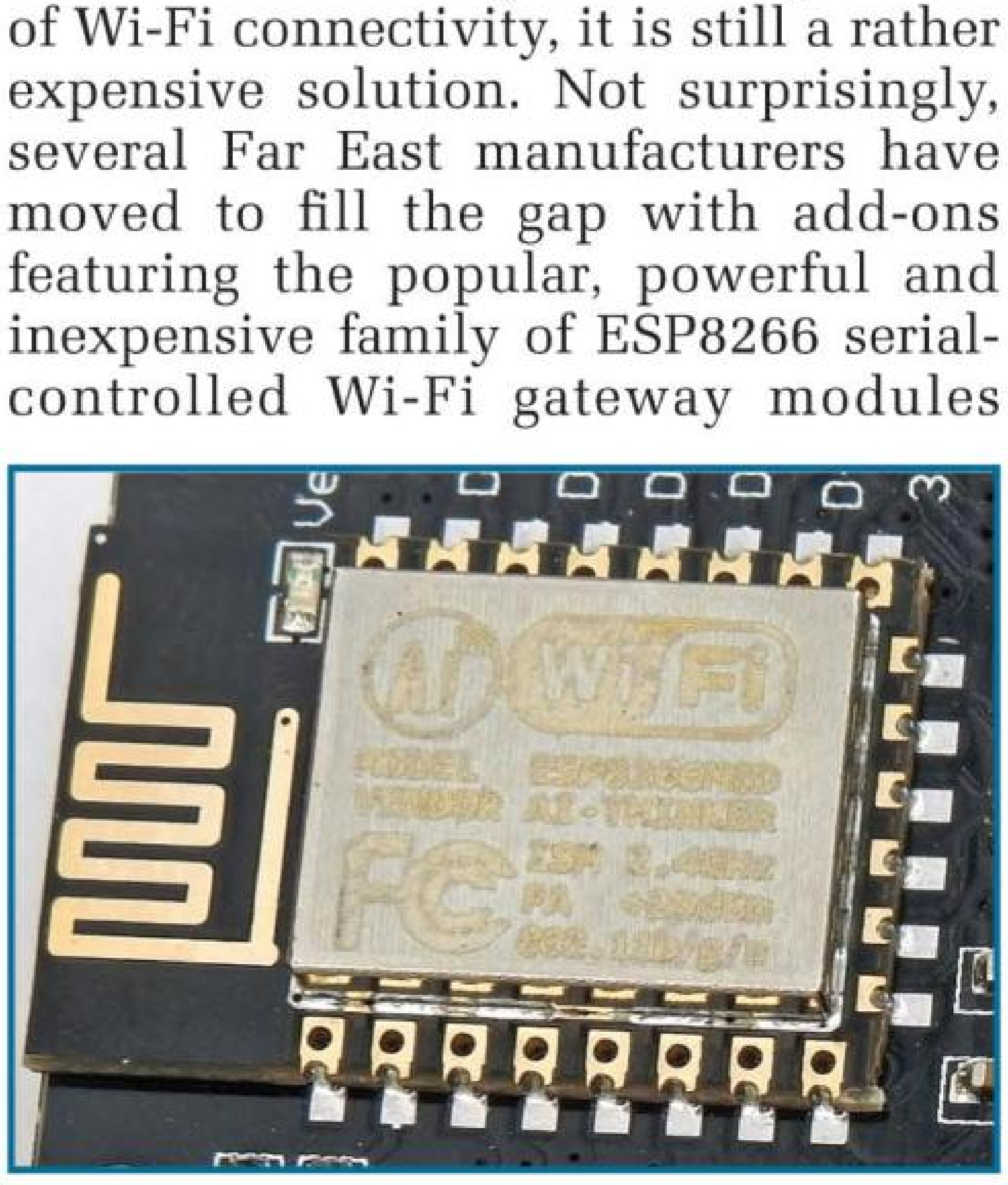


Fig.12.1. ESP8266 serially-controlled Wi-Fi gateway

The ESP8266 SoC

The ESP8266 SoC (system on chip) provides a full TCP/IP stack (see Wi-Fi glossary box). This makes the chip an ideal companion for a basic Arduino such as a Nano or Uno because it allows the Arduino to continue with control applications unencumbered by the demanding task of having to implement network protocols. The ESP8266 is serial-TTL compatible and uses the standard AT command set.

A notable feature of the ESP8266 is that, as well as providing a Wi-Fi gateway, the device can operate as a microcontroller in its own right. It has a 32-bit processor, 64kB RAM and 512kB of external Flash memory, and a variety of interface facilities including GPIO, ADC, SPI and PWM. This makes it possible to use the chip in simple low-cost stand-alone control applications with in-built Wi-Fi connectivity. The ESP8266 SoC is packaged in various forms, the most notable of which are listed in Table 12.1. The pin connections for an ESP12E are shown in Fig.12.2.

Using the ESP8266 Wi-Fi gateway

To use an ESP8266 as a slave with another microcontroller you simply connect the TXD, RXD and ground pins and feed the module with a supply voltage of 3.3V (3.6V maximum). Note that, when operating, the module can demand an appreciable amount of supply current and the VCC supply must be capable of delivering around 300mA. The preferred option would be that of using a suitably rated low-dropout (LDO) voltage regulator fed from an available 5V source. The LDO should be rated at 500mA – but, note that if the host microcontroller chip is a 5V device the RXD data should be level shifted so that a logic high level on this pin will be limited to 3.3V (rather the usual 5V high-state).

Ready-made Wi-Fi shield

If you need a ready-made solution, the Sparkfun ESP8266 Wi-Fi Shield (see Fig.12.3) will provide an easy way of connecting an Uno to the Internet. The Sparkfun features selectable serial lines

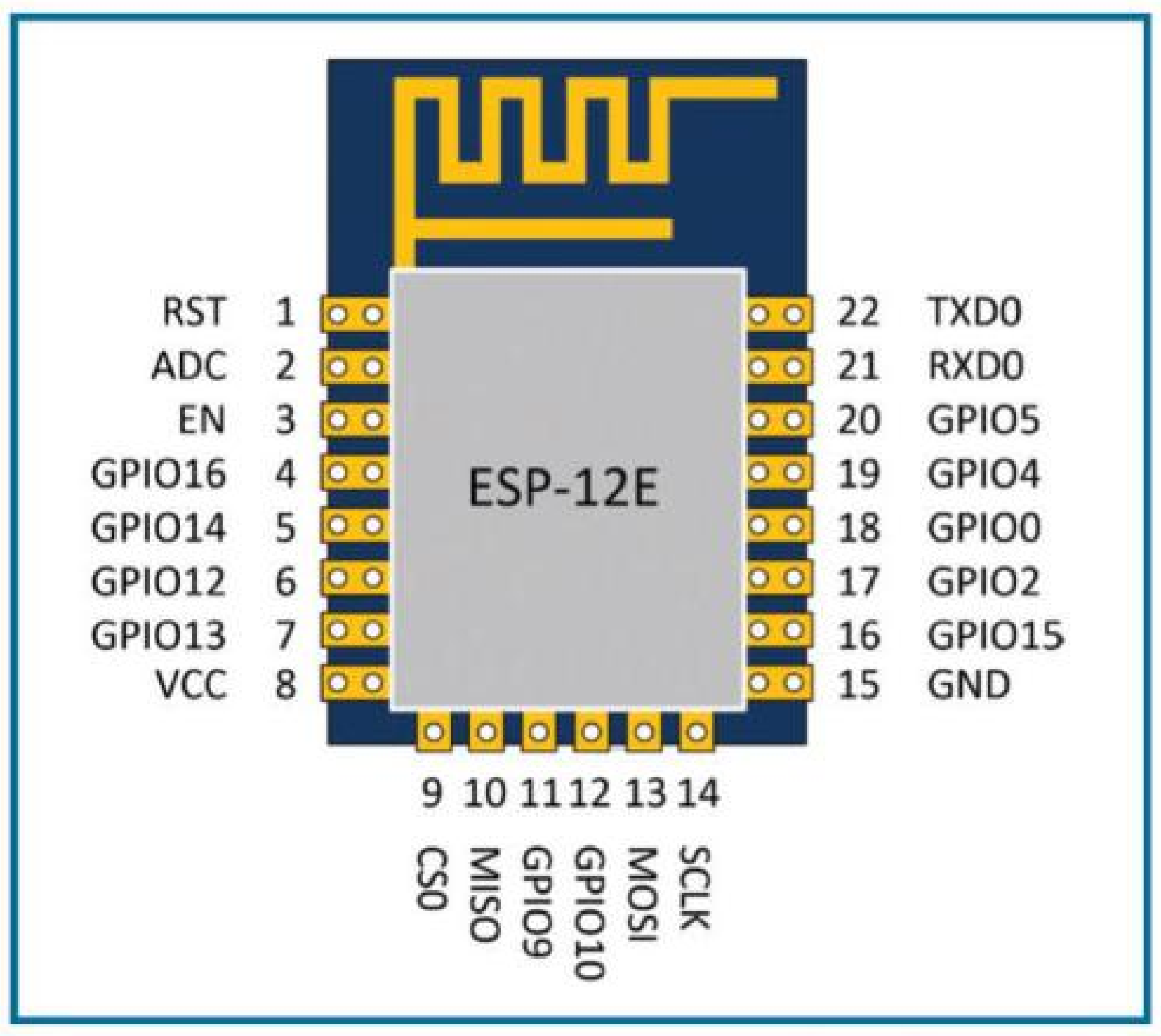


Fig.12.2. Pin connections for the ESP8266E

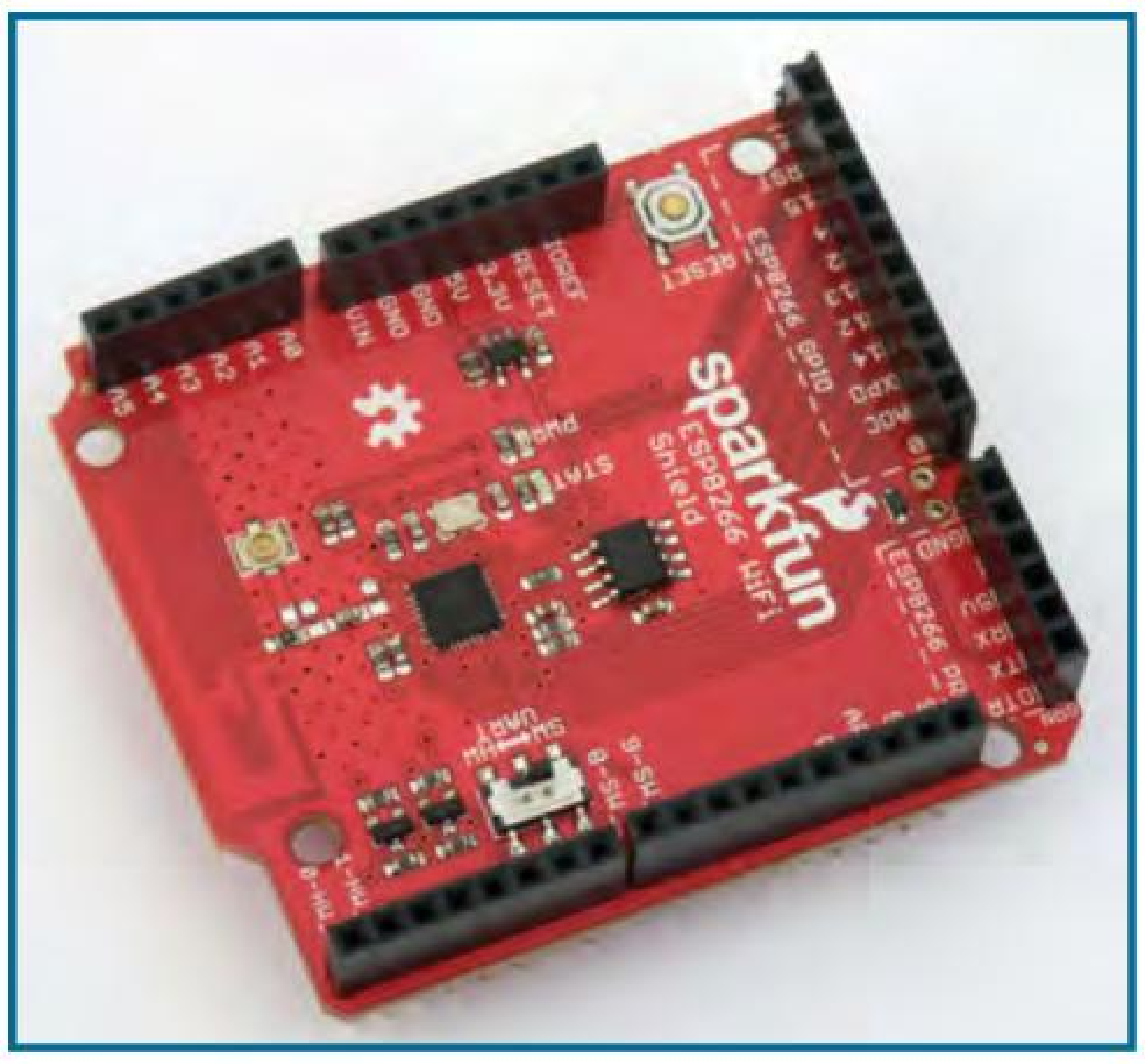


Fig.12.3. Sparkfun ESP8266 Wi-Fi shield

Table 12.1. Some common versions of the ESP8266

Version	Dimensions (mm)	Features
ESP-03	17 × 12	Ceramic antenna; seven GPIO lines
ESP-07	20 × 10	Nine GPIO lines; shielded metal shell; FCC CE certification; built-in ceramic antenna and status LED
ESP-08	17 × 16	Similar to ESP-07 but the antenna can be selected by users
ESP-09	10 × 10	Small SMD; four-layer PCB; 1M byte
ESP-12	24 × 16	Printed PCB antenna; analogue input; metal shield for improved RF performance immunity
ESP-12E	24 × 16	Upgraded version of the ESP-12 with six I/O lines, SPI and improved RF interference immunity; FCC and CE certification
ESP-12F	24 × 16	Four-layer board design; up to 50% improved range; shielded metal enclosure; built-in PCB antenna and 4Mbyte of Flash memory; FCC, CE and RoHS certification
ESP-13	24 × 16	Similar to ESP-12F; printed PCB antenna; improved RF performance; FCC, CE and RoHS certification

that route the TXD and RXD signals to either the Arduino's dedicated hardware serial port (on digital I/O pins 0 and 1) or to a software serial port on digital I/O pins 8 and 9. The active port is selected via an on-board switch. For most applications, the default baud rate of 9600 bps works well and the software serial interface will avoid the need to use the hardware serial interface.

In order to avoid problems with logic-level compatibility, the Sparkfun Wi-Fi shield incorporates level shifters for both the TXD and RXD signals. The board has a status LED that provides the indications shown in Table 12.2 (we found this very useful). Further details and a comprehensive *Hookup Guide* are available from Sparkfun at: **https://learn.sparkfun.com/tutorials/esp8266-wifi-shield-hookup-guide**.

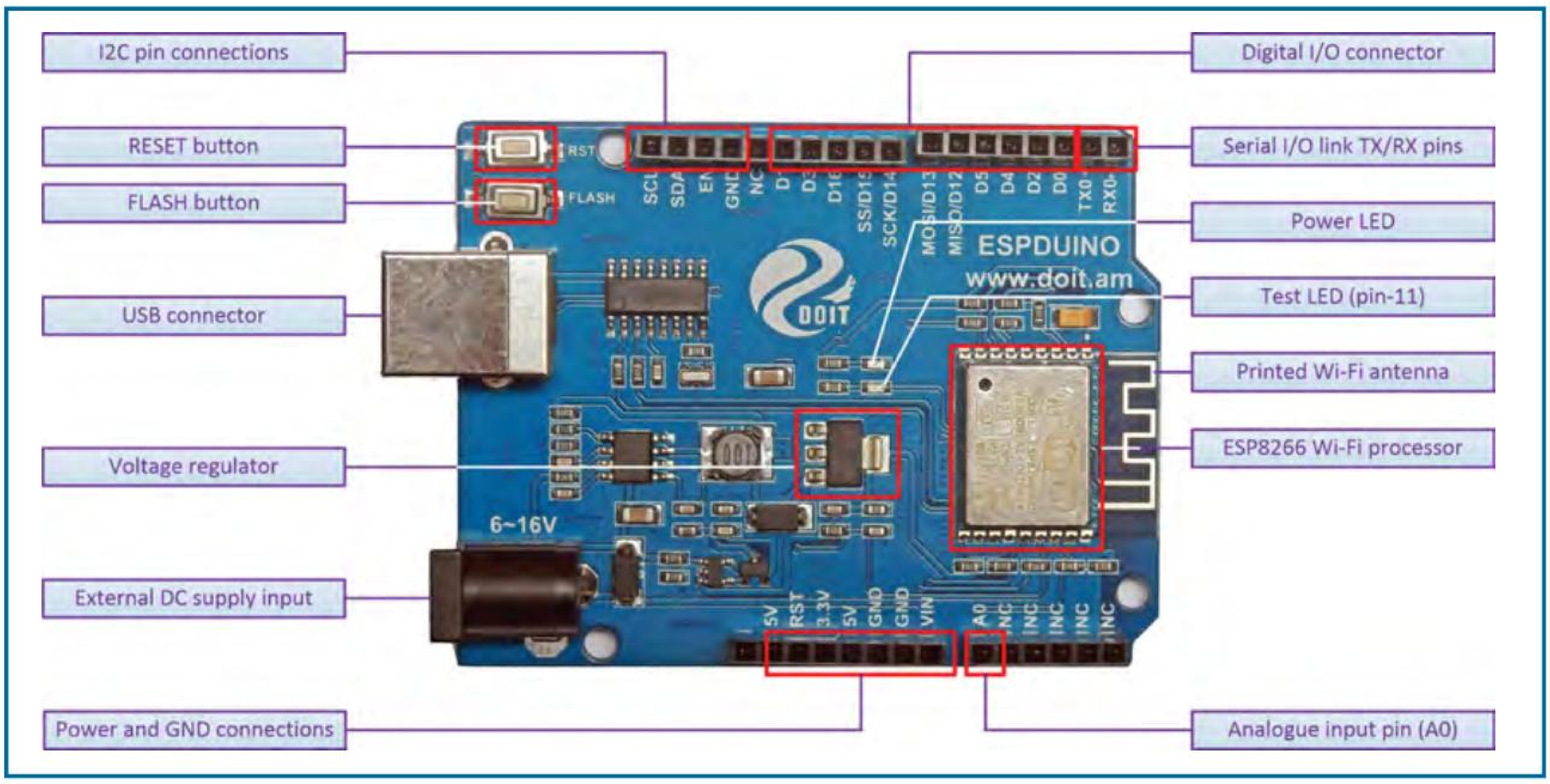

I2C pin connections
RESET button
FLASH button
USB connector
Voltage regulator
External DC supply input
Power and GND connections
Digital I/O connector
Serial I/O link TX/RX pins
Power LED
Test LED (pin-11)
Printed Wi-Fi antenna
ESP8266 Wi-Fi processor
Analogue input pin (A0)

Fig.12.4. The ESPDuino has a footprint, layout and many features in common with the Arduino Uno

Table 12.2. Sparkfun Wi-Fi gateway status indications

LED indication	ESP8266 state	
	Dimensions (mm)	Features
Off	Wi-Fi disconnected and/or not configured	Wi-Fi disconnected and/or not configured
Blinking	ESP8266 attempting to connect to the AP	ESP8266 waiting for incoming connections
On	ESP8266 connected to the AP	Device(s) connected to the ESP8266 AP

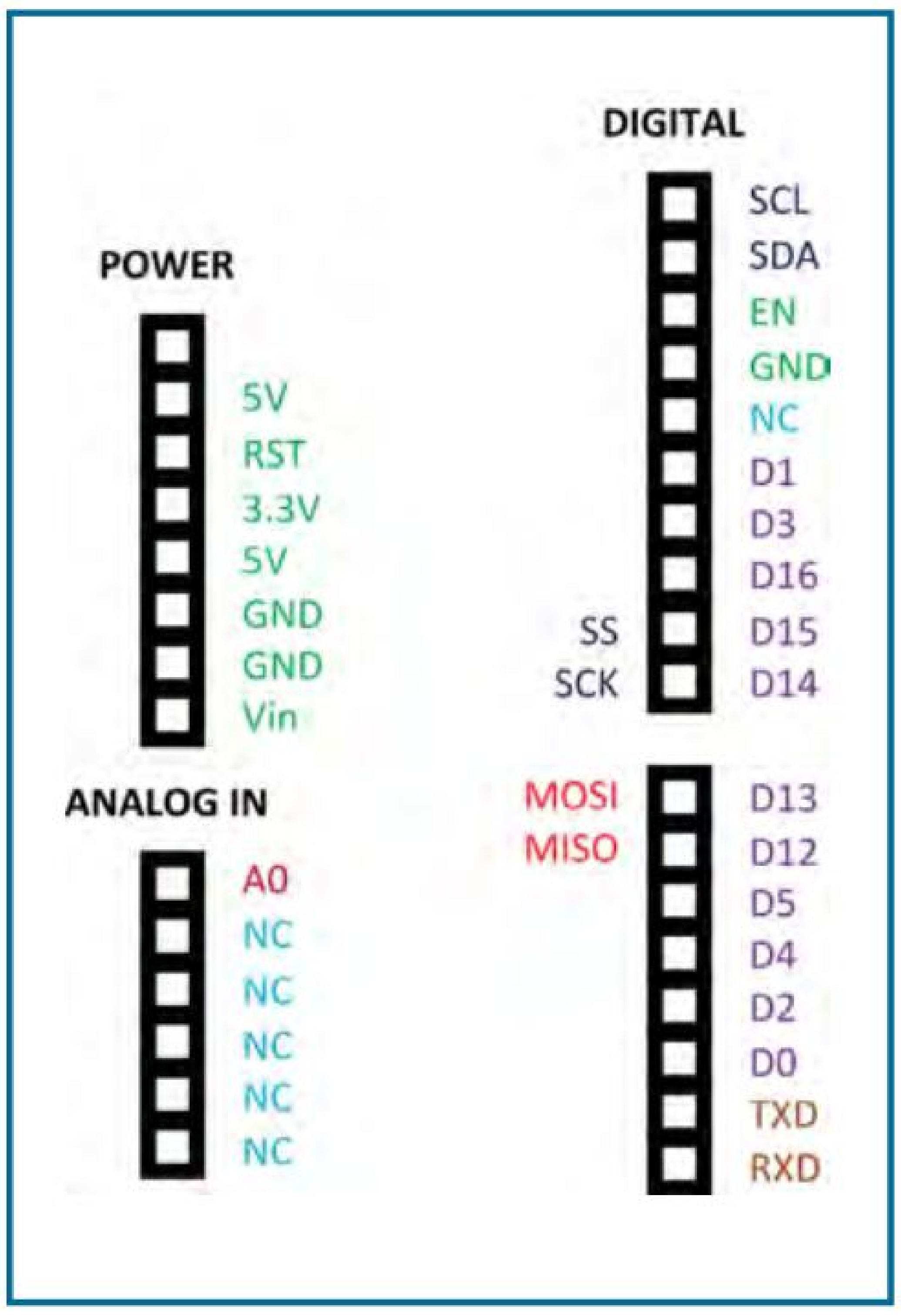

DIGITAL
POWER
5V
RST
3.3V
5V
GND
GND
Vin
ANALOG IN
A0
NC
NC
NC
NC
NC
SCL
SDA
EN
GND
NC
D1
D3
D16
SS
D15
SCK
D14
MOSI
D13
MISO
D12
D5
D4
D2
D0
TXD
RXD

Fig.12.5. ESPDuino header connections

Enter the ESPDuino

Earlier, we mentioned that, as well as being able to provide a Wi-Fi gateway, the ESP8266 incorporates all of the features of a small microcontroller. With some versions of the ESP8266, the I/O facilities are comparable (though not quite as comprehensive) as those of an Arduino Uno. This makes the chip an ideal candidate for Internet of Things (IoT) applications; ie, control applications that send and receive data via the Internet.

Developed by DOIT (the Shenzen 'Doctors of Intelligence and Technology') the ESPDuino (see Fig.12.4) harnesses the ESP8266 as a complete stand-alone microcontroller with features similar to those of an Uno, but with the added advantage of built-in Wi-Fi connectivity. The header pin connections for the ESPDuino are shown Fig.12.5. Later, in this final instalment of *Teach-In 2016* we will show how the ESPDuino can be put to good use in a simple IoT application.

Wi-Fi glossary

Access Point (AP)
An AP acts as the bridge between a wireless network client and a hard-wired network.

Advanced Encryption Standard (AES)
AES is a symmetric block encryption protocol. AES is used in WPA2 (as well as some other protocols) as a means of encrypting data with a high level of security and relatively low CPU overhead.

Basic Service Set Identifier (BSSID)
The BSSID is the Media Access Control (MAC) address of the AP.

Bluetooth
Bluetooth is a standard that supports short-range wireless connectivity between peripheral devices such as keyboards, mice, cameras, phones, printers and speakers.

Bridge
A bridge is the name given to a network device that interconnects two dissimilar networks. For example, an AP acts as a bridge between a wireless network and a wired network.

Hotspot
When an AP is set up specifically to provide Internet access for casual users it is referred to as a 'hotspot'. Hotspots are often available in hotels, restaurants and other publicly accessible locations. Hotspots often don't require any authentication or offer any encryption and so they should be treated with care due to the reduced level of security.

Media Access Control (MAC)
MAC is a communications protocol that distinguishes network devices using a unique MAC address. Some devices have MAC addresses assigned during manufacture, while others can be allocated a MAC address using programming software.

Multiple Input/Multiple Output (MIMO)
MIMO signaling uses multiple transceivers and antennas to improve throughput and range of a wireless network.

Near Field Communications (NFC)
NFC is a technology that allows mobile and portable devices to exchange data based on proximity. NFC technology is becoming widely used for data transfer using mobile phones and smart payment devices, but it has a wide range of other applications such as transferring images from a camera to a laptop.

Open Network
An open wireless network provides a network connection without the need for a password, passphrase or other means of authentication. Open networks operate as hotspots (see earlier) and provide free Internet access to anyone within range.

Passphrase
A password, or combination of words (ie, a passphrase) is commonly used to provide authentication of users in a wireless network. WEP (see later) uses a fixed 40-bit or 104-bit passphrase, while WPA and WPA2 can use a passphrase of arbitrary length.

Pre-shared Key (PSK)
When a passphrase is shared between users before it is needed it is often referred to as a pre-shared key (PSK). PSKs are used in WEP, WPA, and WPA2 (see later). In these networks each client needs the same PSK in order to join the network.

Router
A wireless router is an AP (see earlier) that provides Internet connectivity that can be shared between network-connected devices.

Service Set Identifier (SSID)
SSID is the name given to a wireless network. The SSID can be broadcast by an AP or can be kept hidden (in which case any device needing to connect to the network must know the SSID as well as the PSK – see earlier).

TCP/IP protocol stack
As data moves through successive protocol layers it is assembled and wrapped into packets for transmission and then disassembled and unwrapped for reception. When TCP/IP is used (see Part 9 of *Teach-In 2016*) the successive layers and the processes involved are referred to as a TCP/IP protocol stack.

Transport Layer Security (TLS)
TLS is a network protocol used to encrypt and authenticate data. TLS is based on the use of a certificate to facilitate the exchange of a public key that is then used as a means of encrypting a session key.

Wired Equivalent Privacy (WEP)
WEP is the original encryption scheme used in wireless networks. WEP uses a 40-bit or 104-bit PSK, but due to the limited security that it provides WEP is normally only found in applications where the data does not need to be protected.

Wi-Fi Protected Access (WPA)
WPA is a security protocol for wireless networks that was designed to replace WEP and uses encryption that makes it more secure.

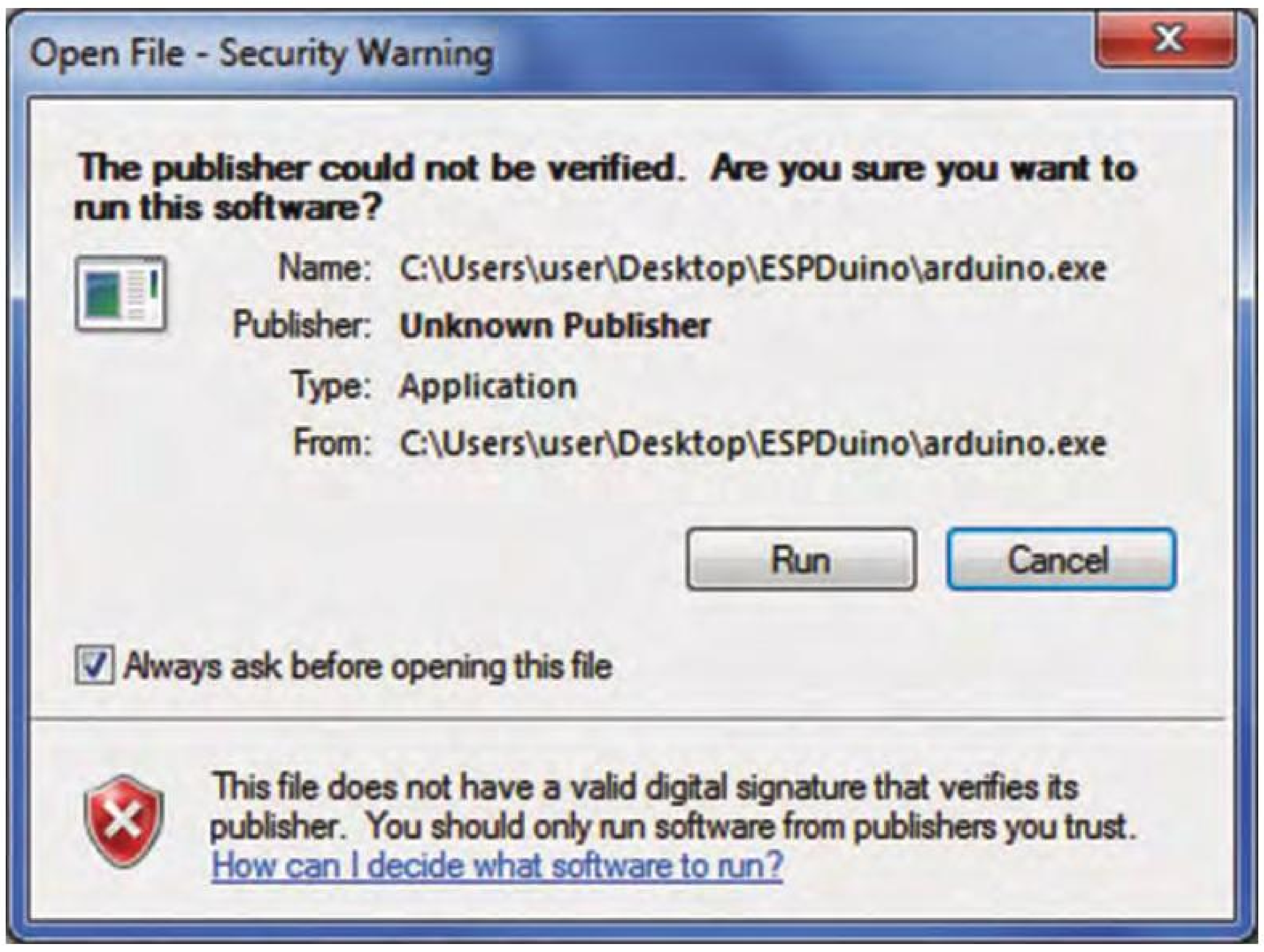
Wi-Fi Protected Access v2 (WPA2)
WPA2 currently provides the strongest encryption protocol available for use with wireless networks. WPA2 uses AES (see earlier) and offers a high level of data security.

Wi-Fi Protected Setup (WPS)
WPS is designed to make it easy to add one or more additional Wi-Fi clients to an existing WPA or WPA2-protected wireless networks. WPS PSKs can be transferred to a new device in various ways including a USB key or by means of NFC techniques (see earlier).

Coding Quickstart : Configuring the ESPDuino's IDE

The ESPDuino is programmed in much the same as any other Arduino board, but first you will need to download a version of the Arduino's IDE designed specifically for the ESPDuino. This can be obtained from the DOIT website by going to **http://en.doit.am/espduino.php**, from where you will be able to transfer the complete IDE in the form of a zipped file to the downloads folder on your computer. The current version is **arduino1.6.8-ESPDuino-2-1.zip**

When the download is complete, you should locate the downloaded zipped file and extract all of the files to your destination folder (we created a desktop folder to accept the files and named it 'ESPDuino'). Note that you will need around 815MB of free space available for the unzipped files. When the files have been unzipped, open the new folder and click on the Arduino IDE application (**Arduino.exe**). A warning message may appear at this stage (see Fig.12.6) in which case you should select the Run option.



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Publisher: **Unknown Publisher**
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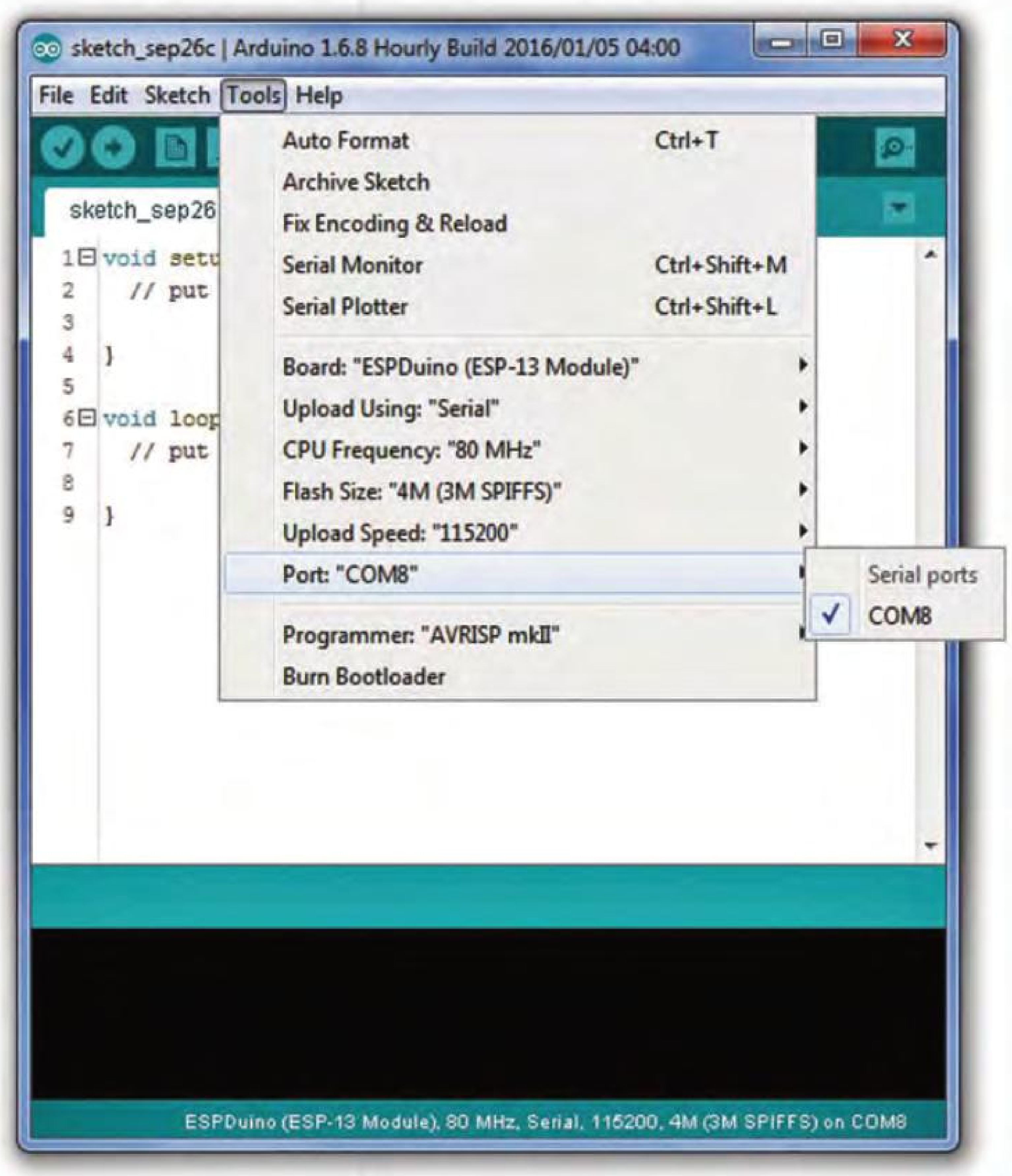
This file does not have a valid digital signature that verifies its publisher. You should only run software from publishers you trust.
How can I decide what software to run?

Fig.12.6. Warning message

You can now connect your ESPDuino to the computer using an available USB port. At this point you might find that your computer may need to install a driver, but if you have an earlier version of the

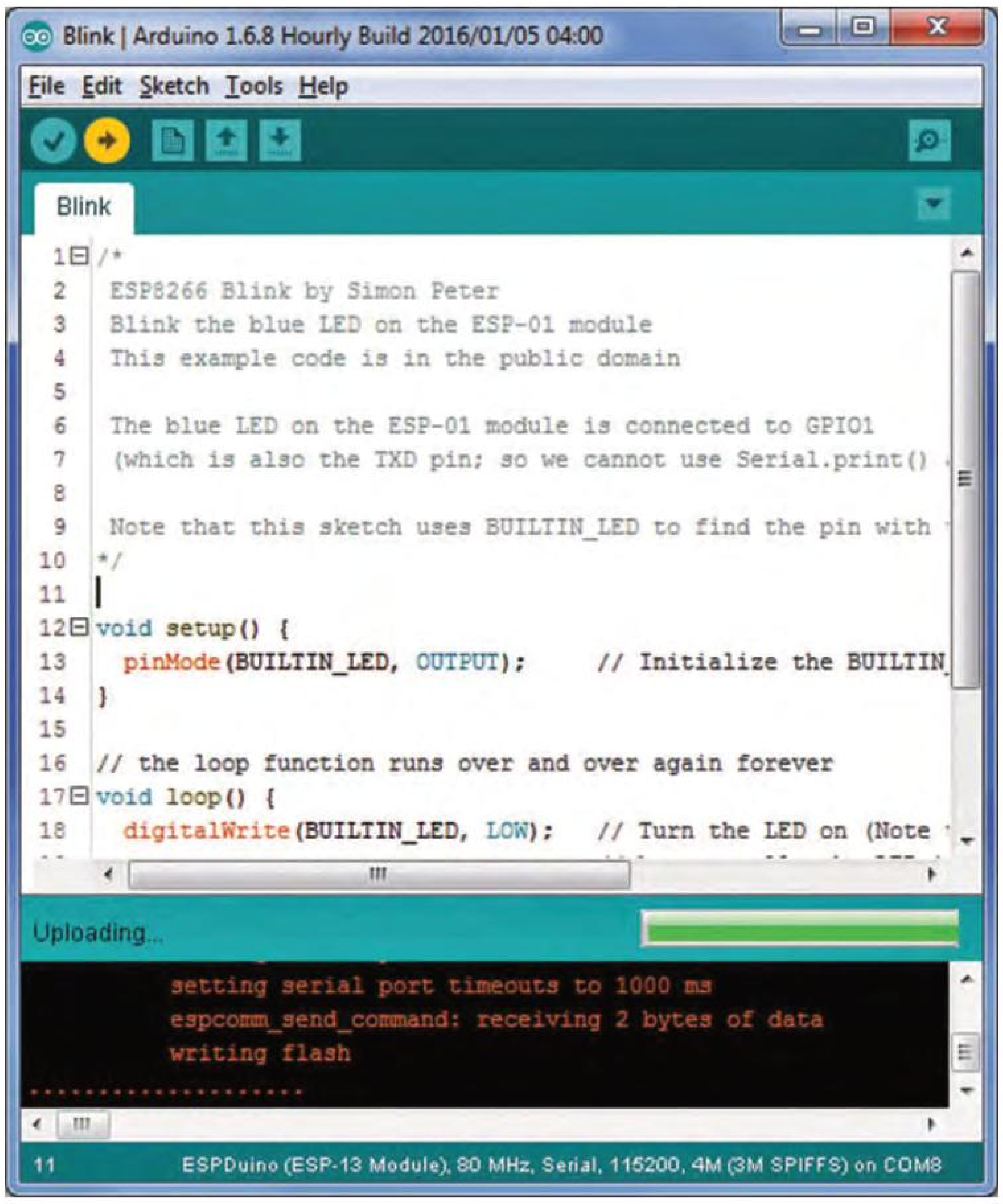

sketch_sep26c | Arduino 1.6.8 Hourly Build 2016/01/05 04:00
File Edit Sketch Tools Help
sketch_sep26
Auto Format Ctrl+T
Archive Sketch
Fix Encoding & Reload
Serial Monitor Ctrl+Shift+M
Serial Plotter Ctrl+Shift+L
Burn Bootloader
Serial ports

```
void setu
  // put

}

void loop
  // put

}
```

Board: "ESPDuino (ESP-13 Module)"
Upload Using: "Serial"
CPU Frequency: "80 MHz"
Flash Size: "4M (3M SPIFFS)"
Upload Speed: "115200"
Port: "COM8"
✓ COM8
Programmer: "AVRISP mkII"

ESPDuino (ESP-13 Module), 80 MHz, Serial, 115200, 4M (3M SPIFFS) on COM8

Fig.12.7. Checking the serial port connection to the ESPDuino


Blink | Arduino 1.6.8 Hourly Build 2016/01/05 04:00
File Edit Sketch Tools Help
Blink

```
/*
 ESP8266 Blink by Simon Peter
 Blink the blue LED on the ESP-01 module
 This example code is in the public domain

 The blue LED on the ESP-01 module is connected to GPIO1
 (which is also the TXD pin; so we cannot use Serial.print()

 Note that this sketch uses BUILTIN_LED to find the pin with
*/

void setup() {
  pinMode(BUILTIN_LED, OUTPUT);     // Initialize the BUILTIN
}

// the loop function runs over and over again forever
void loop() {
  digitalWrite(BUILTIN_LED, LOW);   // Turn the LED on (Note
```

Uploading...

```
        setting serial port timeouts to 1000 ms
        espcomm_send_command: receiving 2 bytes of data
        writing flash
....................
```

11 ESPDuino (ESP-13 Module), 80 MHz, Serial, 115200, 4M (3M SPIFFS) on COM8

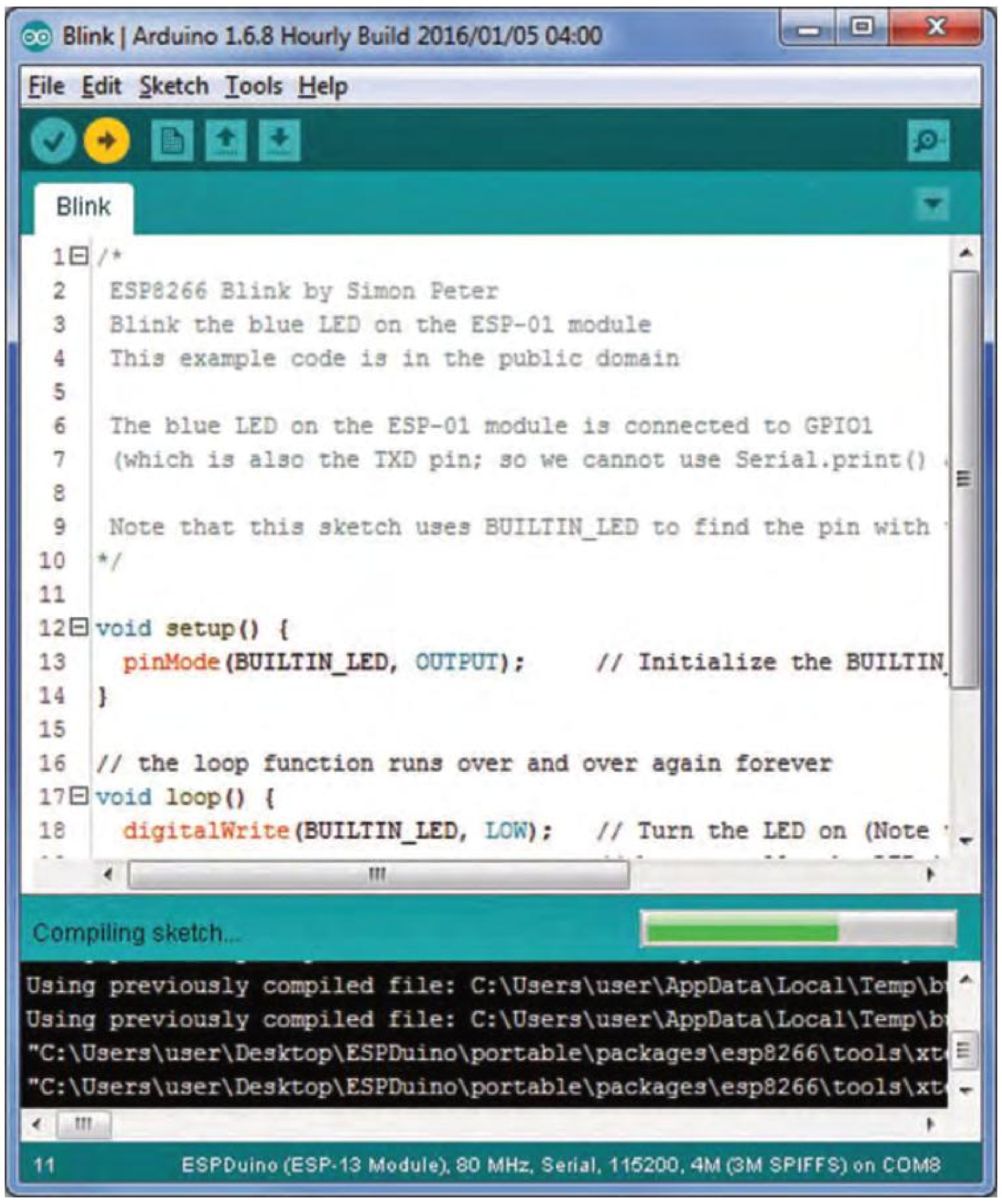
Fig.12.9. Messages from the IDE during the process of writing to the ESPDuino's Flash memory

Arduino IDE this will probably not be required. Depending on your operating system version this may be automatic, but if you experience problems you can refer to the documentation files available from the DOIT website (see earlier).

When the IDE window has opened you should first click on Tools in the main menu and then select Board: ESPDuino (ESP-13 Module) from the Board Manager drop-down list. This will configure the IDE for use with your ESPDuino board. Next go back to the Tools menu and check that a serial COM port is available (see Fig.12.7).

Having installed and configured the IDE it is important to get familiar with the process of uploading code to the ESPDuino's Flash memory. This is a little more complex than when uploading code to an Uno, but a little practice will help you get to grips with it. Start by going to the Files menu, then select Examples and then ESP8266 followed by Blink. Load the example code into your IDE prior to uploading it to the ESPDuino.

To start the process of transferring your code to the ESPDuino's Flash memory you will first need to press the FLASH button (see Fig.12.4) and keep it held down. While the FLASH button is held down you must next press the RESET


Blink | Arduino 1.6.8 Hourly Build 2016/01/05 04:00
File Edit Sketch Tools Help
Blink

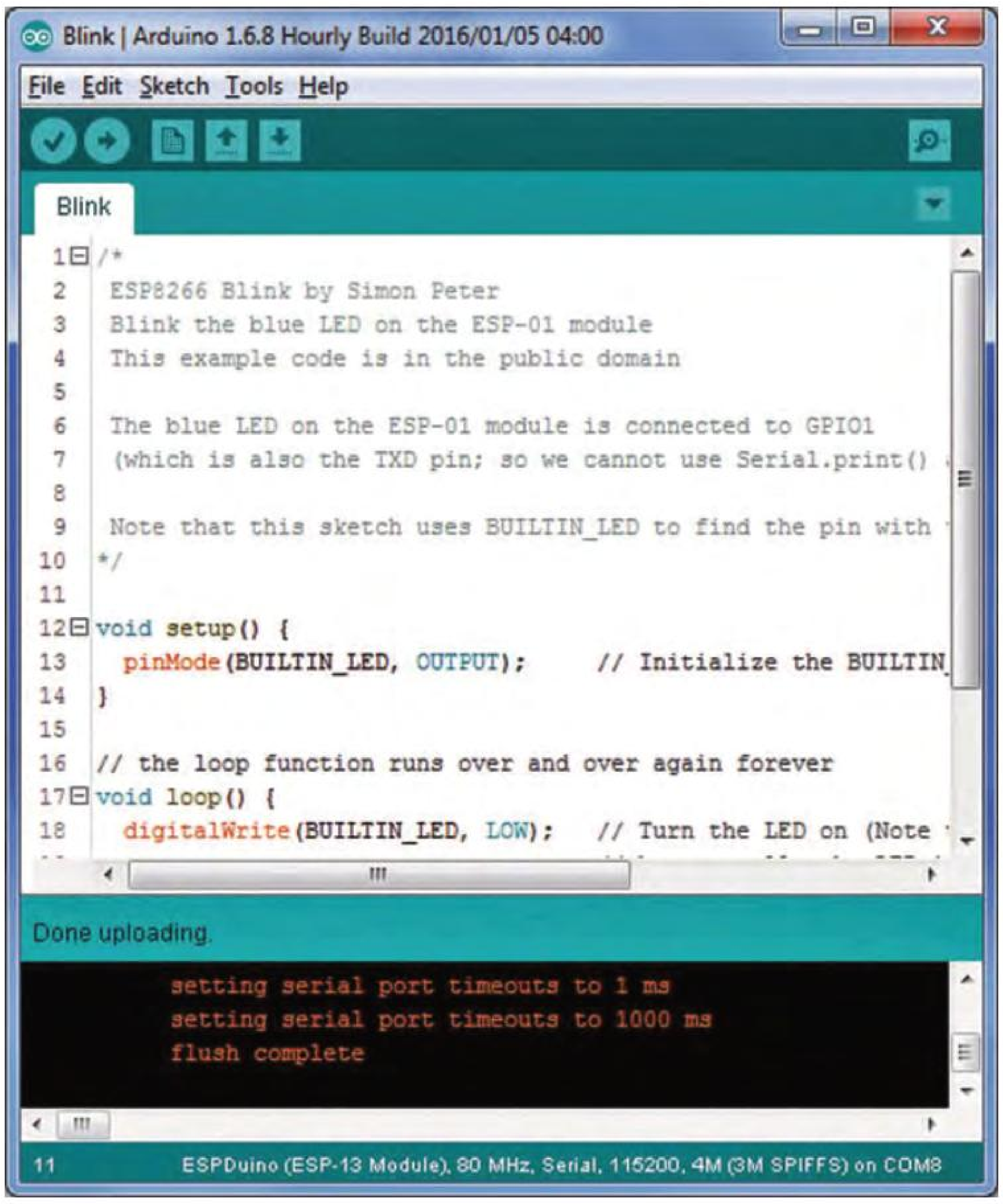
```
/*
 ESP8266 Blink by Simon Peter
 Blink the blue LED on the ESP-01 module
 This example code is in the public domain

 The blue LED on the ESP-01 module is connected to GPIO1
 (which is also the TXD pin; so we cannot use Serial.print()

 Note that this sketch uses BUILTIN_LED to find the pin with
*/

void setup() {
  pinMode(BUILTIN_LED, OUTPUT);     // Initialize the BUILTIN
}

// the loop function runs over and over again forever
void loop() {
  digitalWrite(BUILTIN_LED, LOW);   // Turn the LED on (Note
```

Compiling sketch...

```
Using previously compiled file: C:\Users\user\AppData\Local\Temp\b
Using previously compiled file: C:\Users\user\AppData\Local\Temp\b
"C:\Users\user\Desktop\ESPDuino\portable\packages\esp8266\tools\xt
"C:\Users\user\Desktop\ESPDuino\portable\packages\esp8266\tools\xt
```

11 ESPDuino (ESP-13 Module), 80 MHz, Serial, 115200, 4M (3M SPIFFS) on COM8

Fig.12.8. Compiler messages from the IDE when compiling code for the ESPDuino


Blink | Arduino 1.6.8 Hourly Build 2016/01/05 04:00
File Edit Sketch Tools Help
Blink

```
/*
 ESP8266 Blink by Simon Peter
 Blink the blue LED on the ESP-01 module
 This example code is in the public domain

 The blue LED on the ESP-01 module is connected to GPIO1
 (which is also the TXD pin; so we cannot use Serial.print()

 Note that this sketch uses BUILTIN_LED to find the pin with
*/

void setup() {
  pinMode(BUILTIN_LED, OUTPUT);     // Initialize the BUILTIN
}

// the loop function runs over and over again forever
void loop() {
  digitalWrite(BUILTIN_LED, LOW);   // Turn the LED on (Note
```

Done uploading.

```
        setting serial port timeouts to 1 ms
        setting serial port timeouts to 1000 ms
        flush complete
```

11 ESPDuino (ESP-13 Module), 80 MHz, Serial, 115200, 4M (3M SPIFFS) on COM8

Fig.12.10. Messages from the IDE confirming completion of the flash process

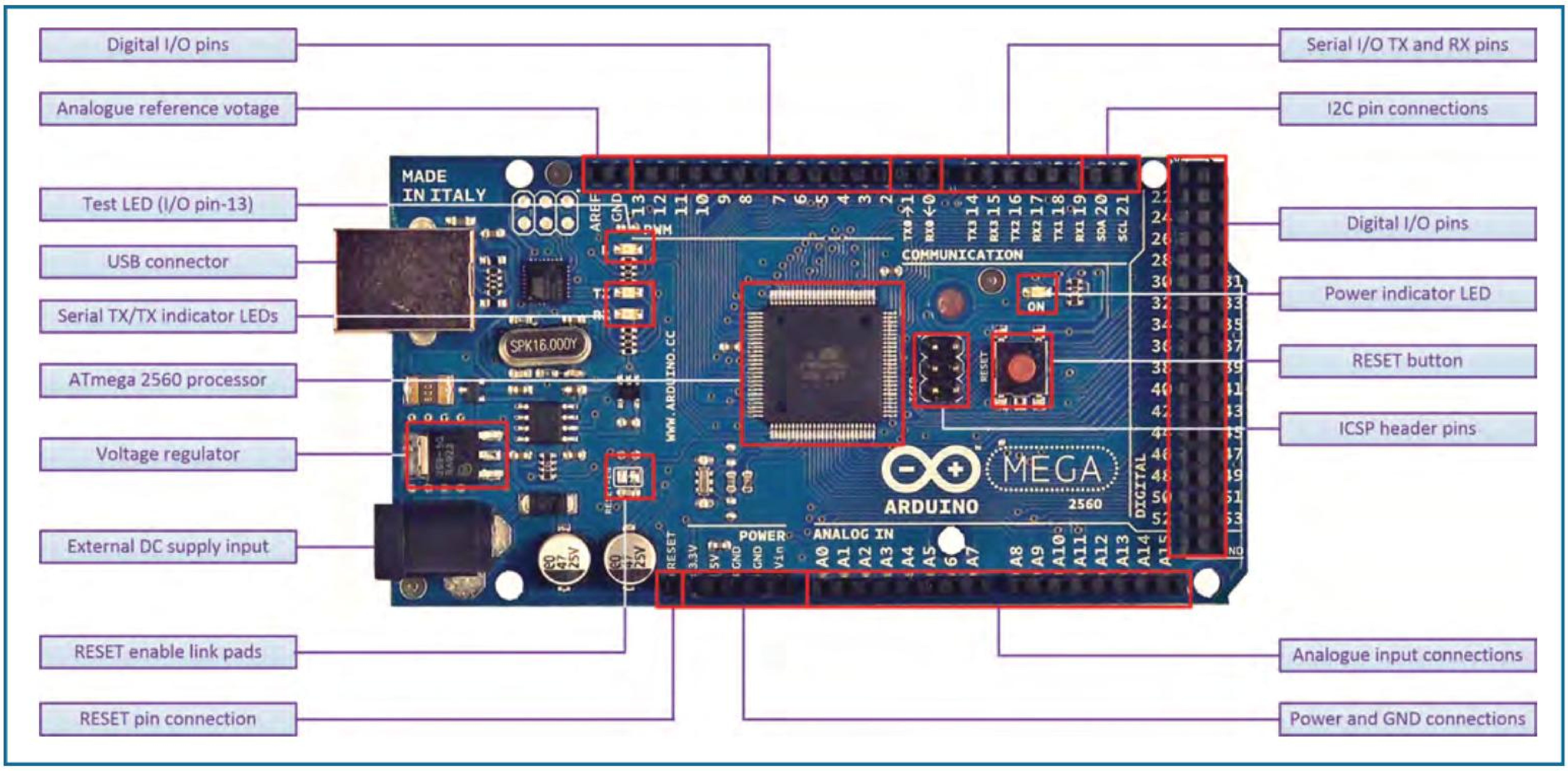

Digital I/O pins
Analogue reference votage
Test LED (I/O pin-13)
USB connector
Serial TX/TX indicator LEDs
ATmega 2560 processor
Voltage regulator
External DC supply input
RESET enable link pads
RESET pin connection
Serial I/O TX and RX pins
I2C pin connections
Digital I/O pins
Power indicator LED
RESET button
ICSP header pins
Analogue input connections
Power and GND connections

Fig.12.11. Arduino Mega board layout

button for a few seconds, after which you must release the RESET button (see Fig.12.4). Since the space around these two buttons is a little tight we found that it was best to use a single finger with a rolling action, first placed on the FLASH button and then rolled to operate and release the RESET button before finally releasing the FLASH button. This might sound a little more complicated than it is, but we have become aware that new users often fail to appreciate the importance of operating these two buttons – *in the correct sequence!*

Having prepared the ESPDuiono to accept the code into its Flash memory you now only need to select Compile and Upload from within the IDE. When you've done this you should be presented with a screen like that shown in Fig.12.8. Note the messages reporting the compiler's progress that appear in white text in the bottom window of the IDE.

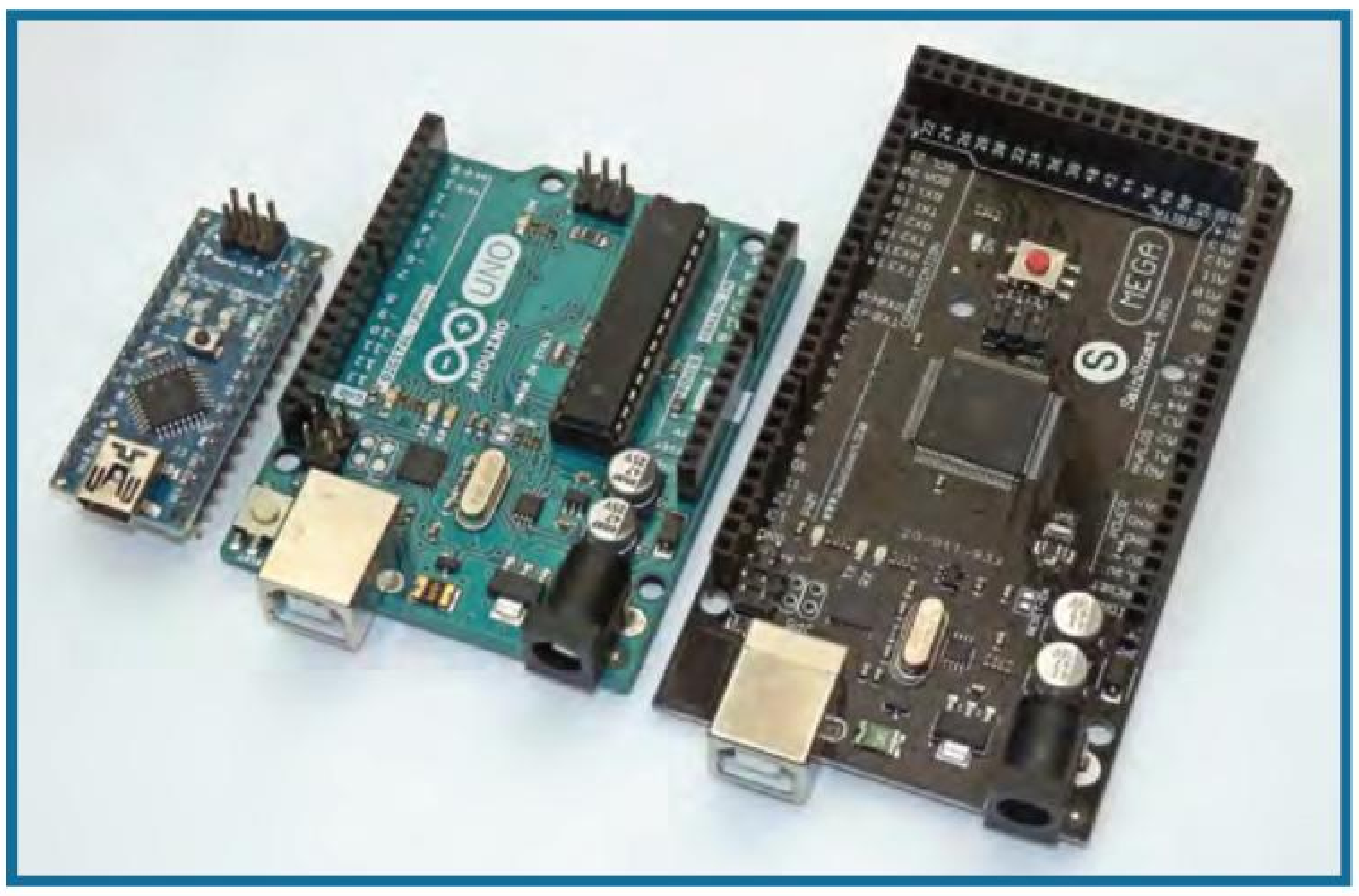


Fig.12.12. Comparison of Nano, Uno and Mega microcontrollers

Table 12.3. Comparison of Arduino models

Arduino model	Mega	Uno	Nano
Microcontroller	ATmega2560	ATmega328P	ATmega328P
Operating voltage	5V	5V	5V
Recommended input voltage range	7-12V	7-12V	7-9V
CPU speed	16MHz	16MHz	16MHz
Digital I/O pins	54 (14 can provide PWM output)	14 (6 can provide PWM output)	14 (6 can provide PWM output)
Analogue input pins	16	6	8
USB connector	Standard Type B	Standard Type B	Micro Type B
SRAM	8kB	2kB	2kB
Flash memory	256kB	32kB	32kB
EEPROM	4kB	1kB	1kB

When the compilation process has completed the process of writing code to the ESPDuino's Flash memory will begin. The IDE will report its progress (as before) and you will be able to follow the writing process by once again referring to the IDE's bottom window (see Fig.12.9). Note how the message text now appears in red. Finally, and if all has gone well, you should be presented with a confirmation message like that shown in Fig.12.10. When this message appears you will have successfully uploaded your code, which will now be resident in the ESPDuino's on-board Flash memory. The ESPDuino will then perform a reset and the example program will be executed, continuously flashing the ESPDuino's LED on and off.

Arduino Workshop: Using the Arduino Mega

For some large control applications, you might find yourself limited by the Uno or Nano's I/O capability. As a case in point, the Uno's 14 digital I/O lines can quickly become occupied if you need to connect a keypad and an LCD display, together with a number of sensors and relays. Fortunately, there is an easy solution – you can substitute an Arduino Mega for the Uno or Nano.

The Arduino Mega2560 (see Fig.12.11) is based on the ATmega2560 microcontroller. The Mega provides significantly more I/O than an Arduino Uno or Nano, notably 54 digital input/output pins (of which 14 can be used as PWM outputs), 16 analogue inputs, and hardware serial ports (UART). If you consider the Nano (described earlier in Part 7 of our current *Teach-In 2016* series) to be the Uno's little sister, then the Mega is its very much bigger brother (see Fig.12.12).

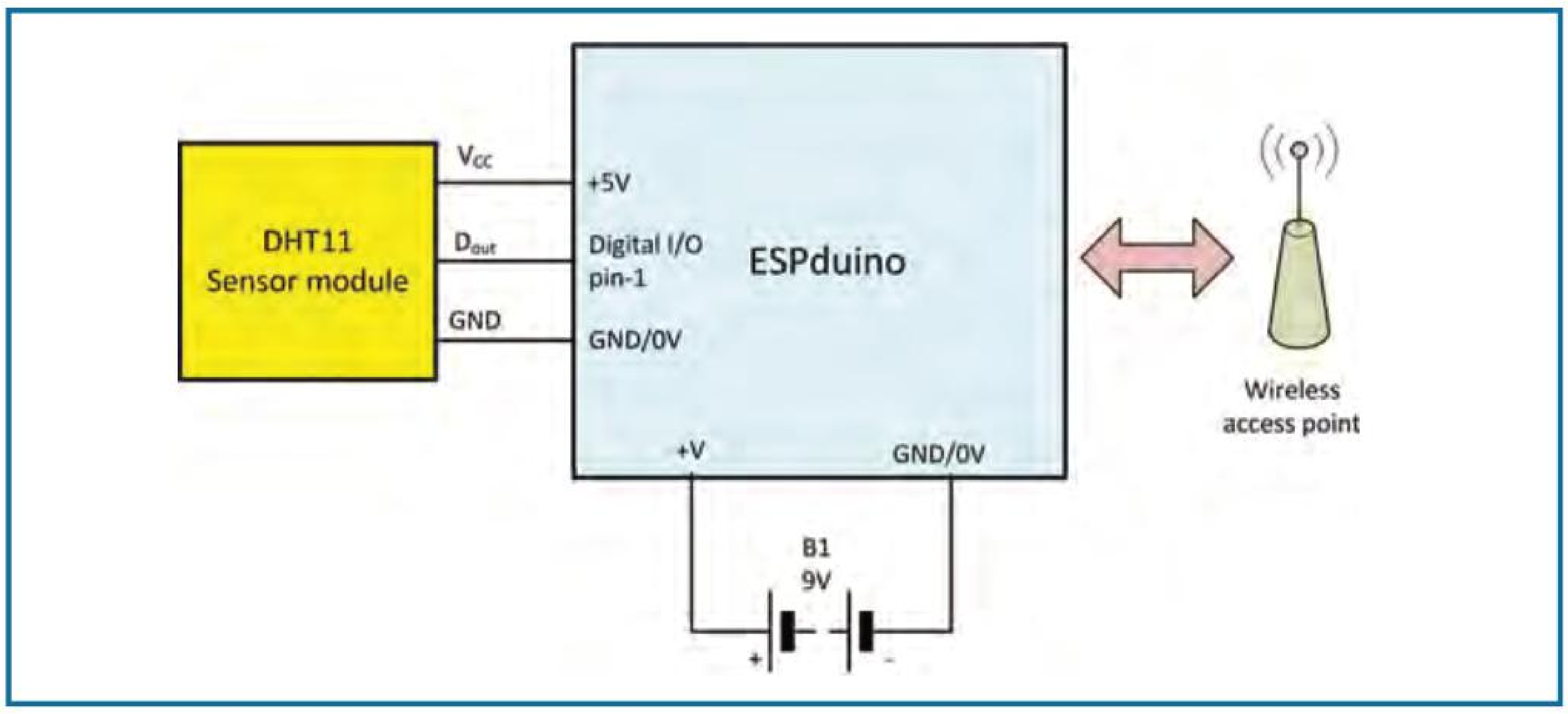


Fig.12.13. ESPDuino IoT environmental monitor complete circuit

The ATmega2560 has 256KB of Flash memory for storing code (of which 8KB is used for the bootloader), 8KB of SRAM and 4KB of EEPROM (which can be read and written with the EEPROM library). Each of the 54 digital pins on the Mega can be used as an input or output, using the `pinMode()`, `digitalWrite()`, and `digitalRead()` functions. In addition to the digital I/O lines (some of which also have specialised functions) the Mega2560 has 16 analogue inputs, each of which provide 10 bits of resolution (ie, 10^{10} = 1024 different values). By default, the input voltage range is from 0 to +5V but, as with the Uno and Nano, it is possible to change the upper limit of the analogue voltage range by making use of the AREF pin and `analogReference()` function.

For communication purposes, the Mega2560 provides four hardware UARTs for serial communication at standard TTL levels but, where necessary, the SoftwareSerial library can be used for serial communication in conjunction with any of the Mega's digital I/O pins. The ATmega2560 also supports I^2C (TWI) and SPI communication.

The Mega board contains a printed link (labelled 'REST-EN') that can be cut to disable the auto-reset. To re-enable this feature, the pads on either side of the link can simply be soldered together. Although most computers provide their own internal protection, over-current protection for the USB port is provided by means of a polyfuse. If more than 500mA is demanded via the Mega's USB port, the fuse will automatically break the connection until the short or overload is removed.

The Mega's I/O pins are rated at a maximum of 40mA per pin and the maximum DC current that can be supplied from the 3.3V pin is 50mA. As with the immensely popular Uno and Nano versions, the Mega can be powered via the USB connection or with an external power supply. The power source is selected automatically. External (non-USB) power can be connected directly to the respective header terminals, GND and Vin. Alternatively, the board can derive its supply from a mains adapter supplying between 7V and 12V and rated at 500mA, or more. The adapter is connected by means of a 2.1mm center-positive power jack. Note that, although the range of operating voltage for a Mega is often quoted as 6V to 20V, when supplied with less than 7V the board may not function correctly and when greater than 12V the regulator can be susceptible to failure with the potential for damage to the board. Finally, it is important to be aware that the Mega2560 differs from all preceding boards in that it does not use the FTDI USB-to-serial driver chip. Instead, it features the Atmega8U2 programmed as a USB-to-serial converter.

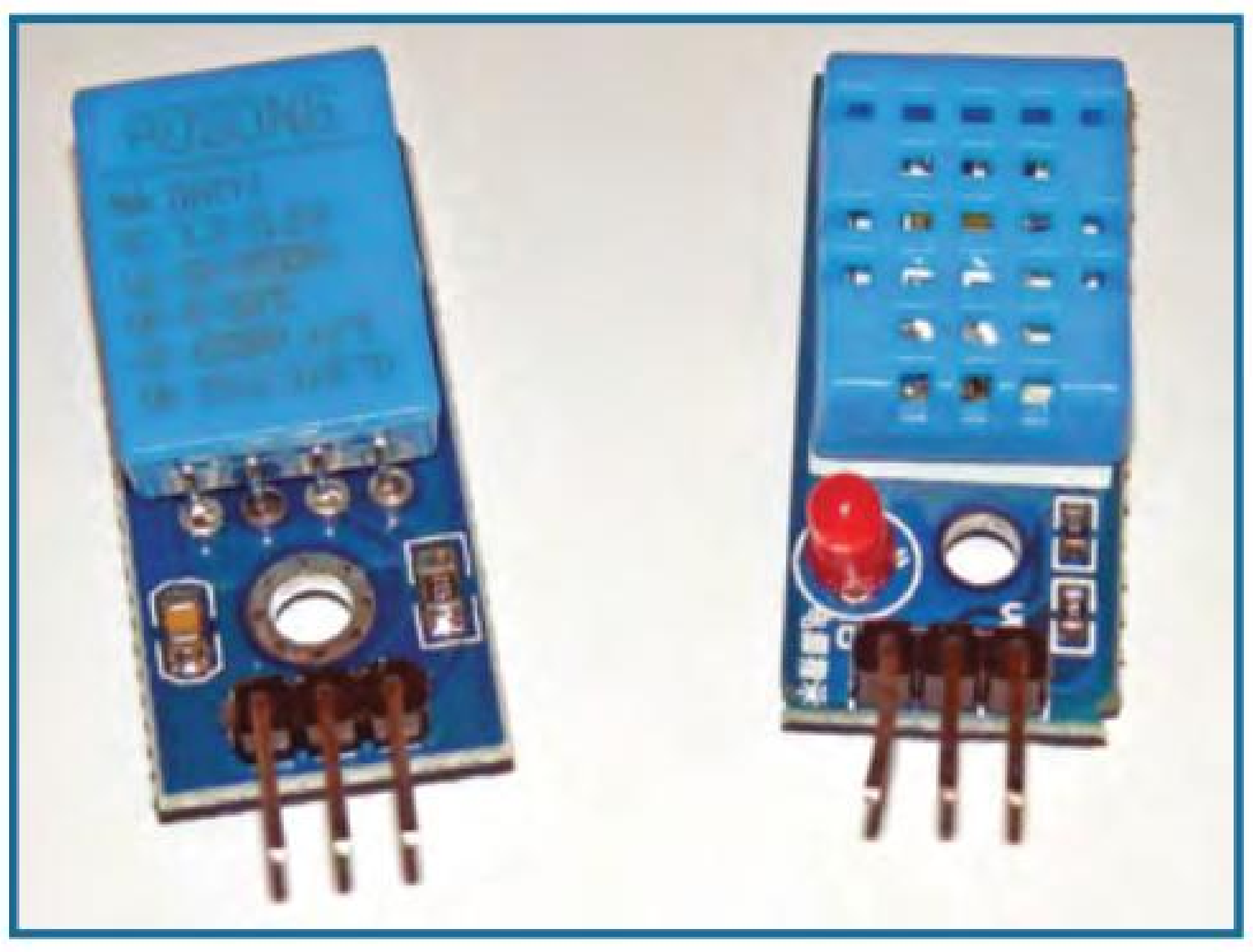


Fig.12.14. Typical DHT-11 temperature and humidity sensors

Get Real : simple ESPDuino IoT environmental monitor

In our final *Get Real* project we will be using an ESPduino in conjunction with a popular low-cost temperature/humidity sensor to construct a weather station that can be interrogated anywhere in the world via the internet. This project demonstrates some very interesting possibilities and will provide you with a great starting point for further experimentation.

The complete circuit of our ESPDuino IoT environmental monitor is shown in Fig.12.13. Temperature and humidity is sensed by means of a DHT-11 combined temperature and humidity sensor (see Fig.12.14). Further details of the sensor can be found in Part 5 of *Teach-In 2016*. The pin connections for the DHT-11 are shown in Fig.12.15 and the complete hardware for the ESPDuino IoT environmental monitor is shown in Fig.12.16.

You will need

ESPDuino
DHT-11 temperature and humidity sensor
Connecting leads
USB cable with miniature USB connector (for programming only)
Computer with an available powered USB port (for programming only)
9V battery, B1

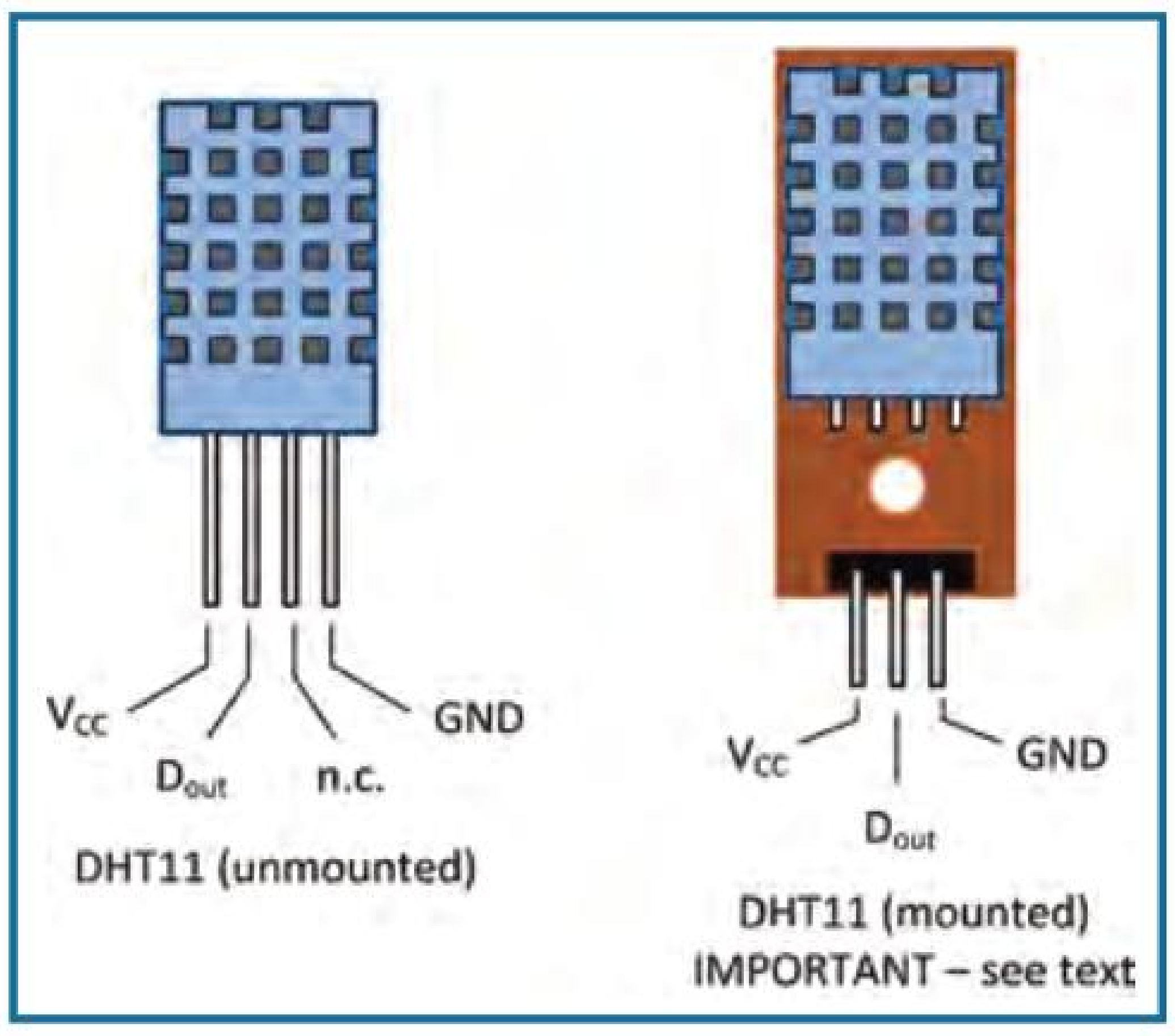


Fig.12.15. Pin connections for DHT-11 temperature and humidity sensor

Before you finalise your code…

Having assembled the hardware for the ESPDuino Internet weather station and before you finalise your code you will need some basic information about the Wi-Fi network that you will be connecting to. In particular, you will need to obtain the network name (SSID) and the network password. In some cases, this information will be printed on a card or panel attached to your AP, but in others it may be included in the AP's documentation.

Setting up a web-based IoT account

Next you will need to open an account with a web-based IoT service. Several providers offer this as a free service, but we chose ThingSpeak because of its links to the excellent MATLAB package, which allows us to easily manipulate and analyse our data. Other IoT services worth considering are Cisco's Cloud Connect, Microsoft's Azure IoT, IBM's Watson, and AWS IoT. With different features and functionality, all of these platforms provide you with a means of connecting your 'things' and making them accessible from a cloud-based service. Note that to take a look at some of ThingSpeak's public channels

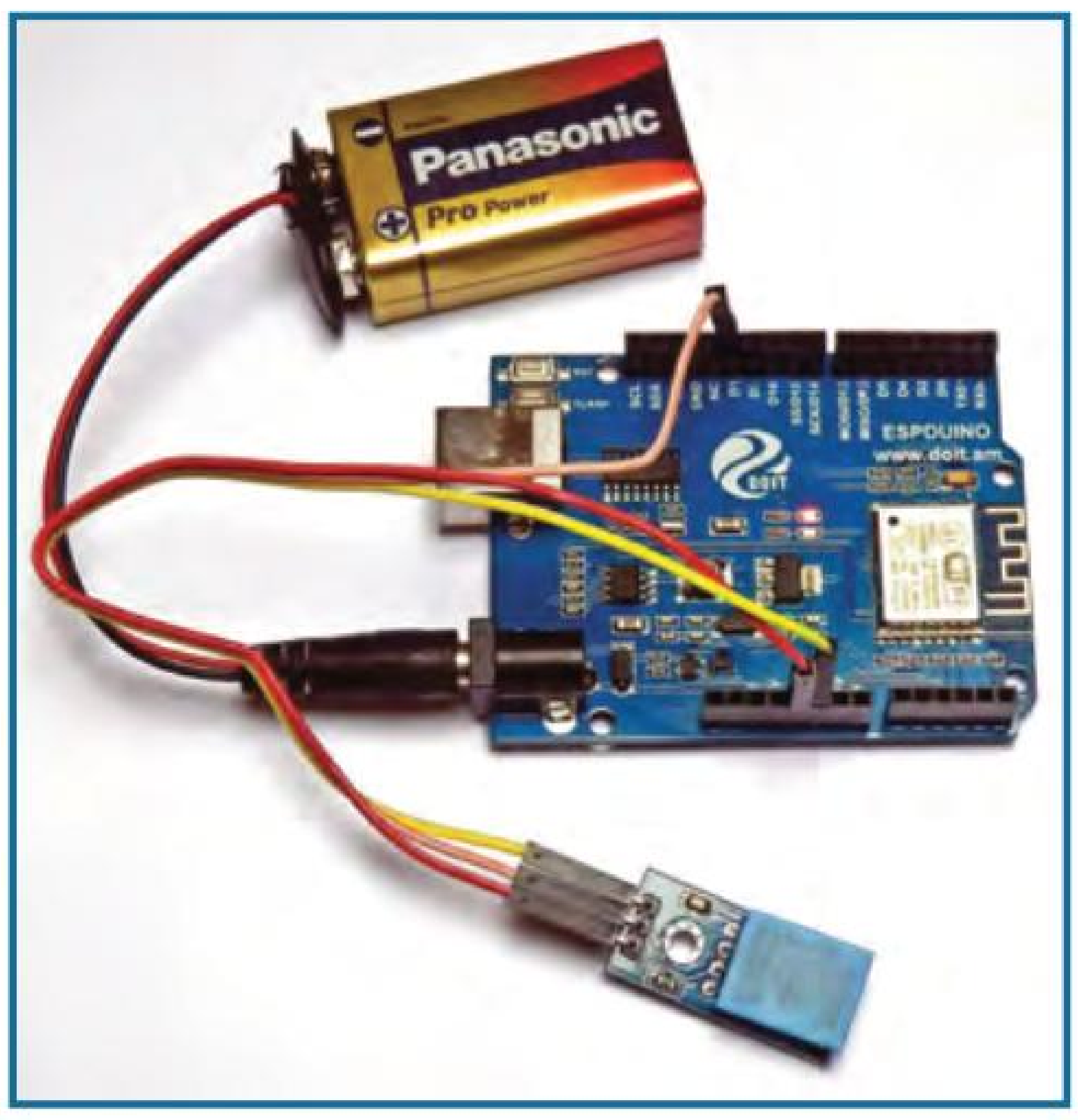


Fig.12.16. The completed ESPDuino IoT environmental monitor

you can visit: **https://thingspeak.com/channels/public** and click on any of the IoT applications that interest you.

Writing and reading your data

To send your humidity and temperature data to ThingSpeak you will need to open a channel to receive the data. ThingSpeak will then allocate a number for your channel and also a set of keys for writing your data and for reading it. You can also choose to make the data 'public' so that it can be viewed without a read key. This might sound a lot more complicated than it is, so we will now take you through the process, step by step.

Go to the ThingSpeak website at: **www.thingspeak.com** and click on Get Started. You will then need to click on Sign Up to create a user account. Having entered a few basic items of information (including an email address) and agreeing to the Terms of Use and Privacy Policy you should click on Create Account. Having opened an account, you should create a new channel to collect and store your data. When you do this, you will first need to name your channel and then enter a short description before identifying each of the data fields that will be used. We just wish to record temperature and humidity data, so we've only used two of the eight available data fields, as shown in Fig.12.17.

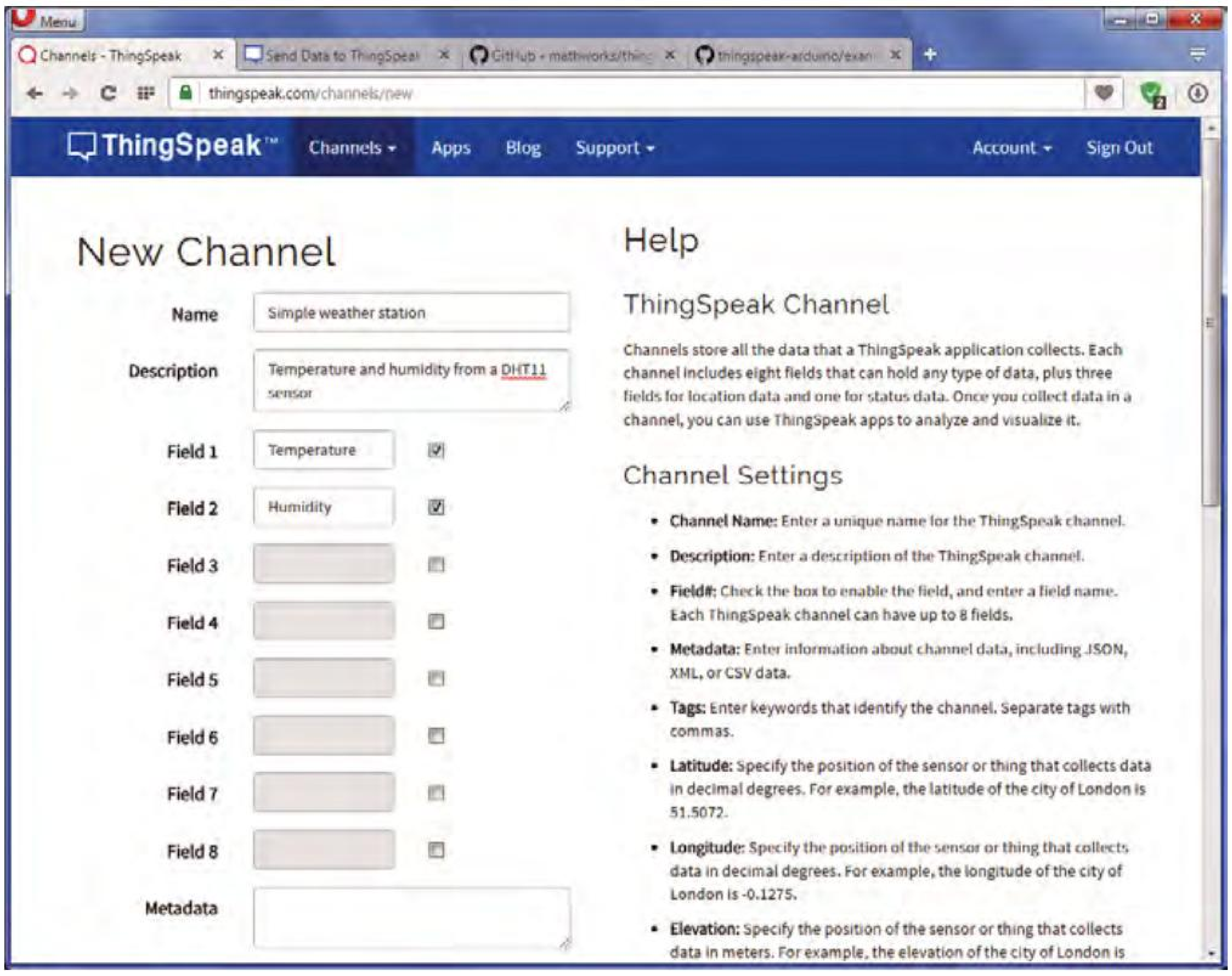
Having entered information about the data that we want ThingSpeak to collect from our Arduino IoT application, you will be allocated read and write keys that you can incorporate in your code, as shown in Fig.12.18. These can be copied and then pasted into your code at the appropriate point.

Code

As previously mentioned, when you first create a ThingSpeak account you will be allocated a channel number and a set of API keys. These will need to be included in your code. The complete code listing for the ESPDuino IoT environmental monitor is shown in Listing 12.1.

The four items that you will need to include specifically for your network and ThingSpeak channel are marked with asterisks in Listing 12.1. You will need to replace these asterisks with your own values for SSID, password, channel number and *write* API key (note that we don't need the *read* API key for this simple application). In addition, you will need to include the following libraries; `ThingSpeak.h` (available from ThingSpeak), `DHT.h`, and `ESP8266WiFi.h`

The libraries are installed in the usual way (see previous *Teach-In 2016* installments for details).



New Channel

Name: Simple weather station

Description: Temperature and humidity from a DHT11 sensor

Field 1: Temperature ☑

Field 2: Humidity ☑

Field 3: ☐

Field 4: ☐

Field 5: ☐

Field 6: ☐

Field 7: ☐

Field 8: ☐

Metadata:

Help

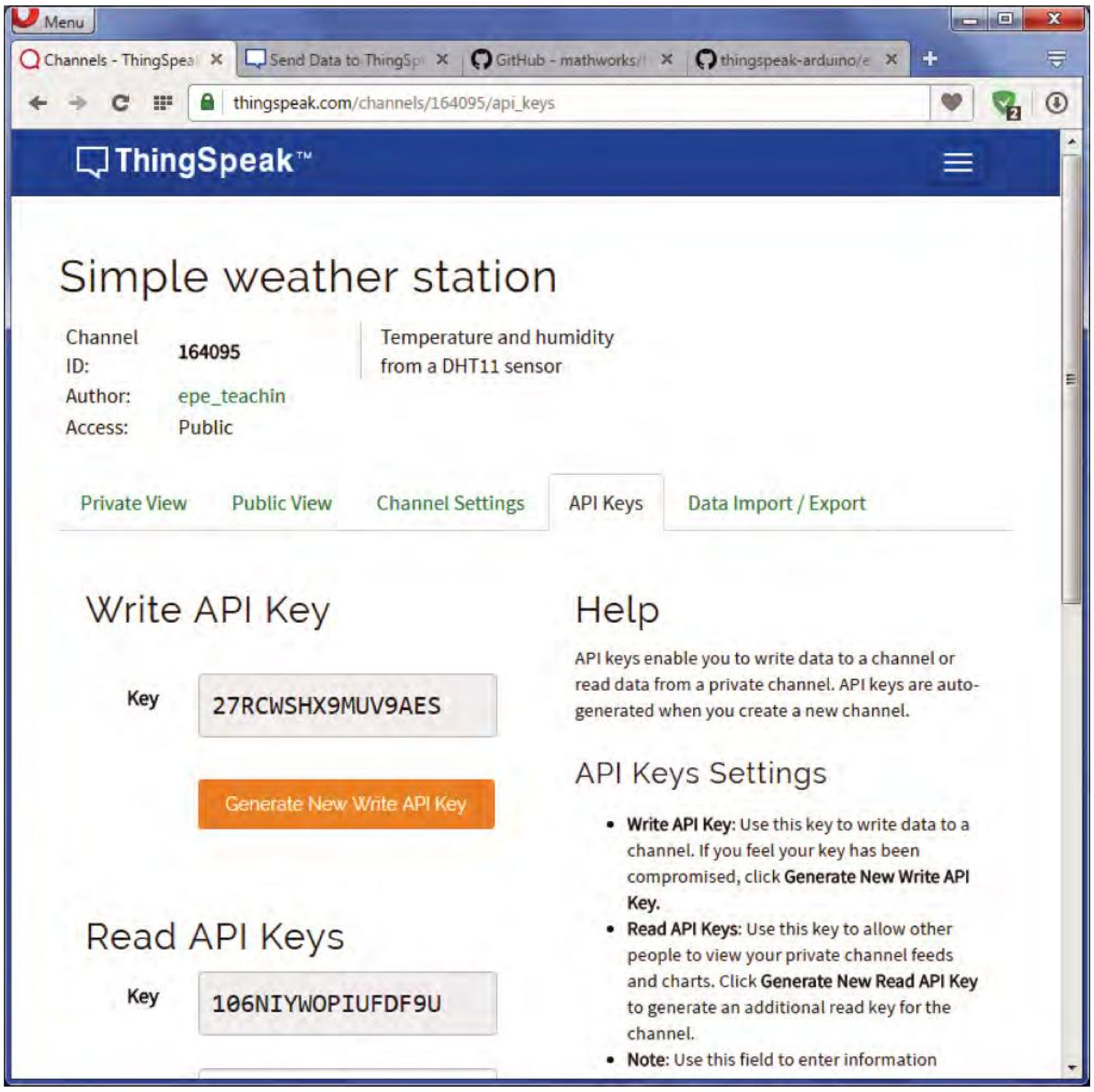
ThingSpeak Channel

Channels store all the data that a ThingSpeak application collects. Each channel includes eight fields that can hold any type of data, plus three fields for location data and one for status data. Once you collect data in a channel, you can use ThingSpeak apps to analyze and visualize it.

Channel Settings

- **Channel Name:** Enter a unique name for the ThingSpeak channel.
- **Description:** Enter a description of the ThingSpeak channel.
- **Field#:** Check the box to enable the field, and enter a field name. Each ThingSpeak channel can have up to 8 fields.
- **Metadata:** Enter information about channel data, including JSON, XML, or CSV data.
- **Tags:** Enter keywords that identify the channel. Separate tags with commas.
- **Latitude:** Specify the position of the sensor or thing that collects data in decimal degrees. For example, the latitude of the city of London is 51.5072.
- **Longitude:** Specify the position of the sensor or thing that collects data in decimal degrees. For example, the longitude of the city of London is -0.1275.
- **Elevation:** Specify the position of the sensor or thing that collects data in meters. For example, the elevation of the city of London is

Fig.12.17. In this simple application we only need to use two of the eight available ThingSpeak data fields



Simple weather station

Channel ID: 164095

Author: epe_teachin

Access: Public

Temperature and humidity from a DHT11 sensor

Write API Key

Key: 27RCWSHX9MUV9AES

Read API Keys

Key: 106NIYWOPIUFDF9U

Help

API keys enable you to write data to a channel or read data from a private channel. API keys are auto-generated when you create a new channel.

API Keys Settings

- **Write API Key:** Use this key to write data to a channel. If you feel your key has been compromised, click **Generate New Write API Key.**
- **Read API Keys:** Use this key to allow other people to view your private channel feeds and charts. Click **Generate New Read API Key** to generate an additional read key for the channel.
- **Note:** Use this field to enter information

Fig.12.18. The two API keys provided for your ThingSpeak channel

Testing and adjustment

As with our previous *Get Real* projects, your code should first be entered into the IDE and then saved before compiling and uploading it to the Uno, as described previously in *Arduino Workshop*. When you have debugged and corrected your code don't forget to save it by clicking on 'File' and 'Save' or 'Save As…'. Finally, click on 'Sketch' and 'Verify/Compile'. Any compilation errors will then be reported in the window at the bottom of the IDE.

When you've corrected any coding errors that the compiler reports you will be ready to upload your code to the ESPDuino using the process that we described earlier on page 39. Next, the ESPDuino will perform a reset and the ESPDuino's LED will flash on and off briefly as first temperature data and then humidity data is sent to ThingSpeak. This process will be repeated every 12 seconds, or so. Depending on the monitoring application and in order to reduce network traffic, you might want to increase this delay to several minutes.

To view your data from the Internet you will need to go to the ThingSpeak website and log in to your channel. Your data can be displayed in various ways and these can be easily configured using ThingSpeak. A typical chart of ThingSpeak temperature data taken over a 6-hour period is shown in Fig.12.19.

Going further

As always, there's a great deal of scope for going further with this month's *Get Real* project. For example:

- Adding more sensors and channels in order to capture other data, such as light level, wind speed and direction. This could, for example, allow you to build a comprehensive remote weather station with data accessible anywhere in the world.
- Setting up a second Arduino (configured as a web client) configured to receive private data from a ThingSpeak channel, displaying it on an LCD screen. This will provide you with a complete remote monitoring system independent of a PC, laptop or mobile phone.
- Adding a standard SD-card module or shield so that, in addition to writing data to a ThingSpeak channel, your data is also stored locally. This will provide you with a means of ensuring that none of the data is lost in the event of a failed network connection.

Listing 12.1 Complete code listing for the ESPDuino weather station

```
/* Simple Internet Weather Station using a DHT11 sensor */
#include “ThingSpeak.h”   // Include the ThingSpeak library
#include <ESP8266WiFi.h>  // Include the ESP8266 WiFi library
#include “DHT.h”          // Include the DHT sensor library
char ssid[] = “***********”;   // Network SSID (name) goes here
char pass[] = “***********”;   // Network password goes here
int status = WL_IDLE_STATUS;
WiFiClient  client;
// Parameters for the DHT11 sensor
#define DHTPIN 1                  // Sensor connected to D1
#define DHTTYPE DHT11
DHT dht(DHTPIN, DHTTYPE, 30);
// Parameter for our ThingSpeak channel
unsigned long myChannelNumber = ******;   // Channel number here
const char * myWriteAPIKey = “***********”;// Write API key here

void setup() {
  pinMode(BUILTIN_LED, OUTPUT);
  WiFi.begin(ssid, pass);
  ThingSpeak.begin(client);
}

void loop() {
  // get the temperature
  float t = dht.readTemperature();
  digitalWrite(BUILTIN_LED, LOW);
  delay(500);
  digitalWrite(BUILTIN_LED, HIGH);
  delay(500);
  // get the humidity
  float h = dht.readHumidity();
  digitalWrite(BUILTIN_LED, LOW);
  delay(500);
  digitalWrite(BUILTIN_LED, HIGH);
  delay(500);
  // Write to Field 1 of the ThingSpeak channel
  ThingSpeak.writeField(myChannelNumber, 1, t, myWriteAPIKey);
  // Write to Field 2 of the ThingSpeak channel
  ThingSpeak.writeField(myChannelNumber, 2, h, myWriteAPIKey);
  delay(9500);   // Wait approx. 12 seconds between readings
}
```

All of these additions could be implemented and easily incorporated into the basic hardware and software. As always, they will provide you with a great opportunity to further develop your coding skills. Finally, to protect your Arduino from inadvertent short circuits and other misconnections it is well worth investing in a small enclosure like the one shown in Fig.12.20. There are many different styles of enclosure but, due to variations in design and tolerances, it is important to ensure that there is access to the GPIO lines used in your particular project.

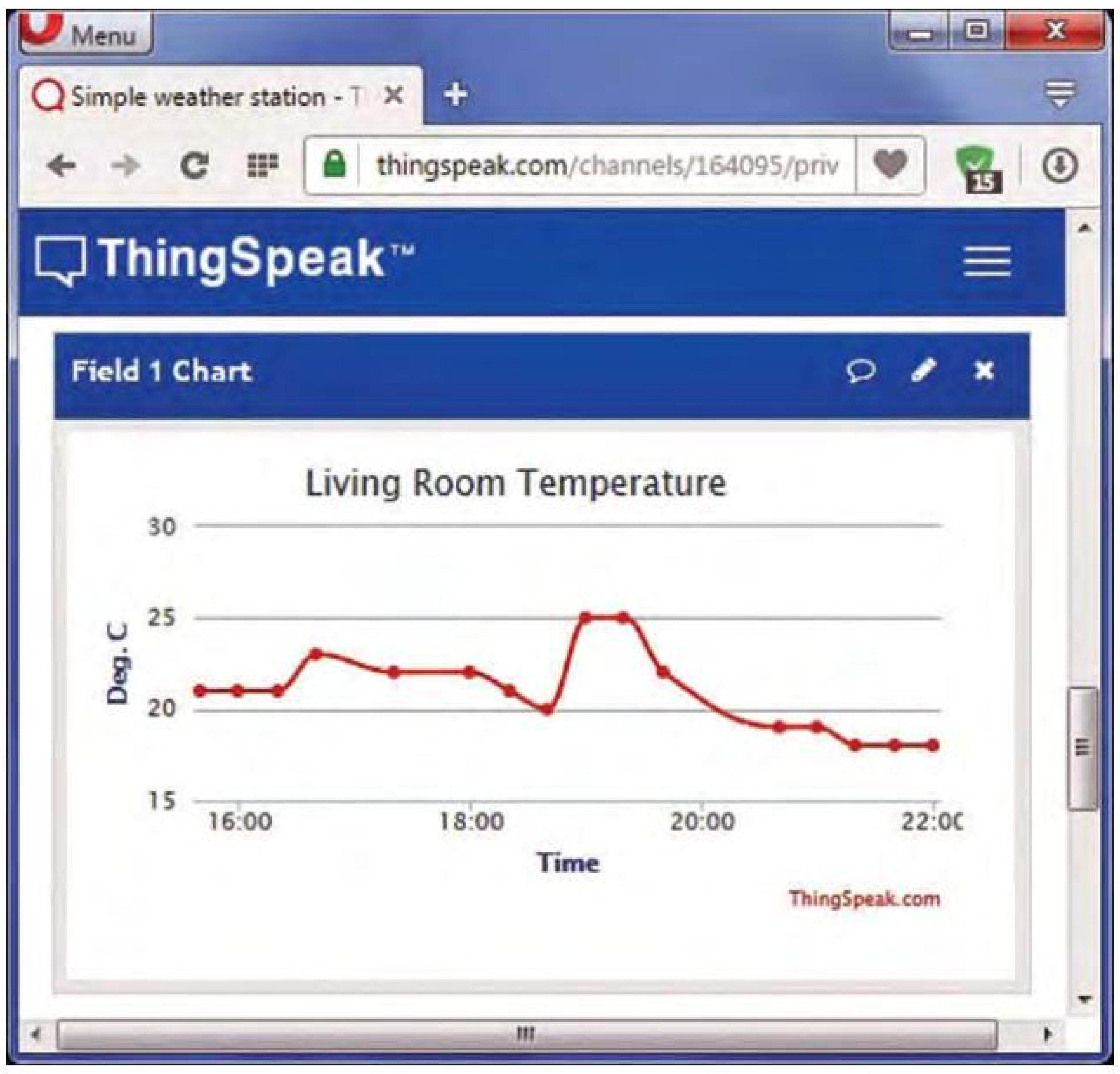


Fig.12.19. A ThingSpeak chart showing IoT data captured by the environmental monitor over a period of six hours

In conclusion

In this final part of our *Teach-In 2016* series we've looked at Wi-Fi solutions for a basic Arduio Uno and taken a detour to look at the ESPDuino with its built-in Wi-Fi support and the added bonus of similar functionality to that of a standard Uno. For those of you that need more I/O capability, both analogue and digital, we've introduced the Uno's big brother, the Arduino Mega. Finally, we have concluded the series by showing you how you can get started with the Internet of Things (IoT). We very much hope that you've enjoyed the series and that it provides you with plenty of food for thought for future projects – there's a vast 'Arduino world' out there for you to explore!

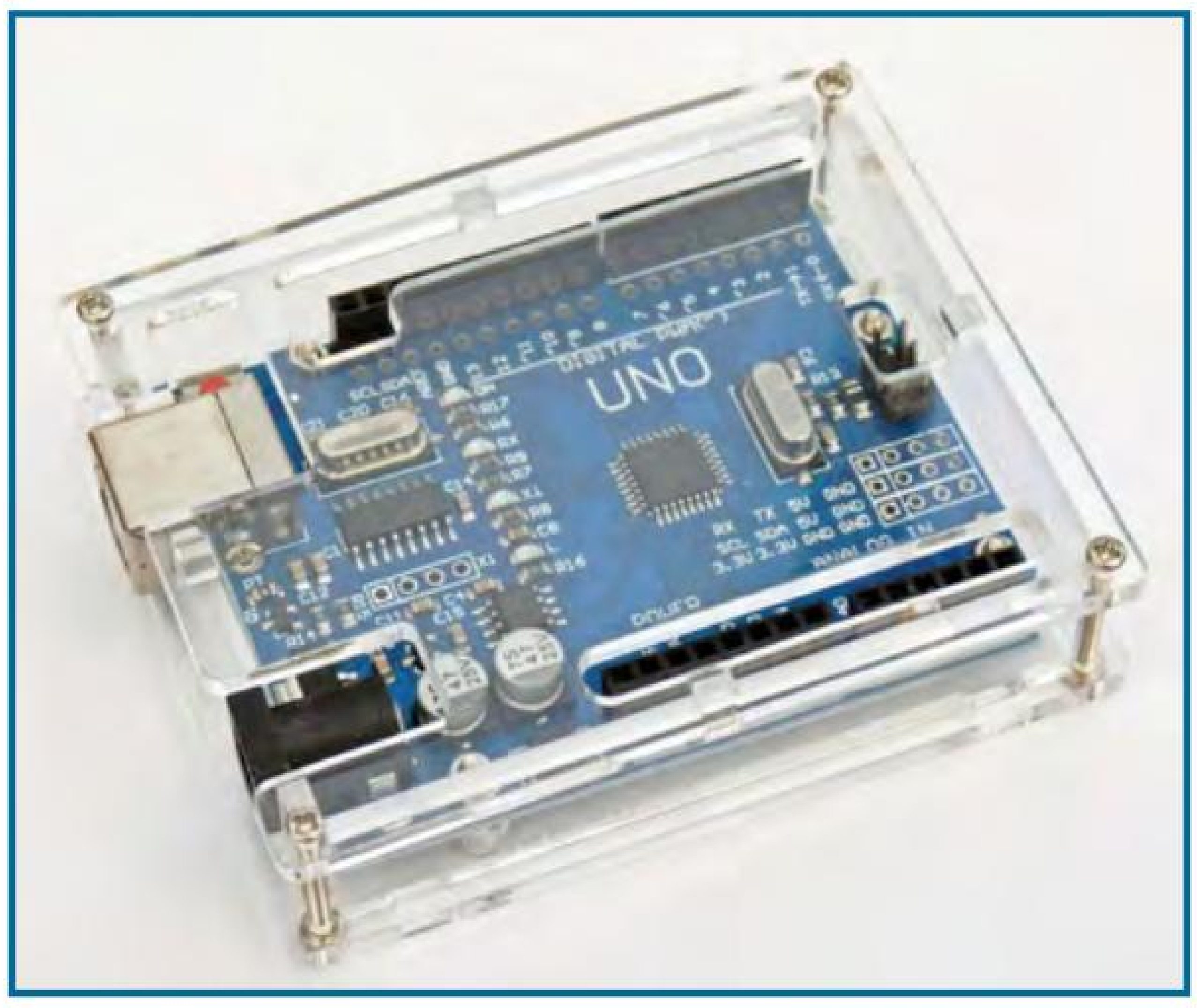


Fig.12.20. Typical low-cost enclosure for an Arduino Uno

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NET WORK

by Alan Winstanley

Smart Alexa

A RECENT Internet-of-Things (IoT) news story reported the plight of a techie fan who bought an IoT-enabled kettle, one that connects via Wi-Fi. It seems the gadget guru then spent 11 tea-craving hours trying to debug network problems before his Amazon Echo could make the kettle boil. Reportedly, he then had to dine in darkness anyway, while his IoT lighting system downloaded some firmware updates. All this at a time when sloppy IoT gadgetry has been blamed for hosting a recent Mirai botneck attack on the US Dyn network, which brought several major sites to their knees for a time.

Last month's *Net Work* introduced Amazon's Echo, a 'smart' loudspeaker that has been a long time coming to the UK. Amazon's gadget hooks to a home Wi-Fi and works in the cloud, using voice recognition to analyse and respond to questions, play music or read eBooks out loud, add items to your Amazon shopping cart or activate compatible IoT hardware. Its built-in digital know-all (Alexa) now speaks with an English accent: our US readers can hear the difference on Amazon's UK website at **http://tinyurl.com/jlcjywj**

Google's rival Home product has yet to arrive, but a teaser video is at **https://madeby.google.com/home**, while Apple's HomeKit relies on an app instead, at least for now (see **www.apple.com/uk/ios/home**).

Meantime the bricks-and-mortar retail trade has gradually re-invented itself after seeing its captive market eroded by the advent of online shopping. To differentiate itself, the British chain Currys PC World led the fightback by launching a 'Reserve & Collect' service that offered the option to shop online at leisure, then collect goods from your nearest store on a day that suits you. In turn, online sellers including Amazon offered delivery to a collection point of your choice. Although retailers often have a price disadvantage over Internet-based suppliers, the same retailers have learned how to harness the power of online marketing for themselves; thanks to the use of cookies, after googling for a 'Teasmade' tea maker – no 'smart' kettle for me! – I was greeted by a series of online ads for Teasmades in Google search pages and third-party websites. Getting a good feel for prices is the key to being a successful buyer, so when I spotted a Google Ad by Currys advertising the same Teasmade at a discount, I decided to try their Reserve and Collect, paying online and collecting next day from a local store without a problem. Surprisingly, the system still relied on a shop assistant writing a note in a desktop diary to say the goods had been collected, so their point-of-sales (POS) systems are not as fully integrated as they could be.

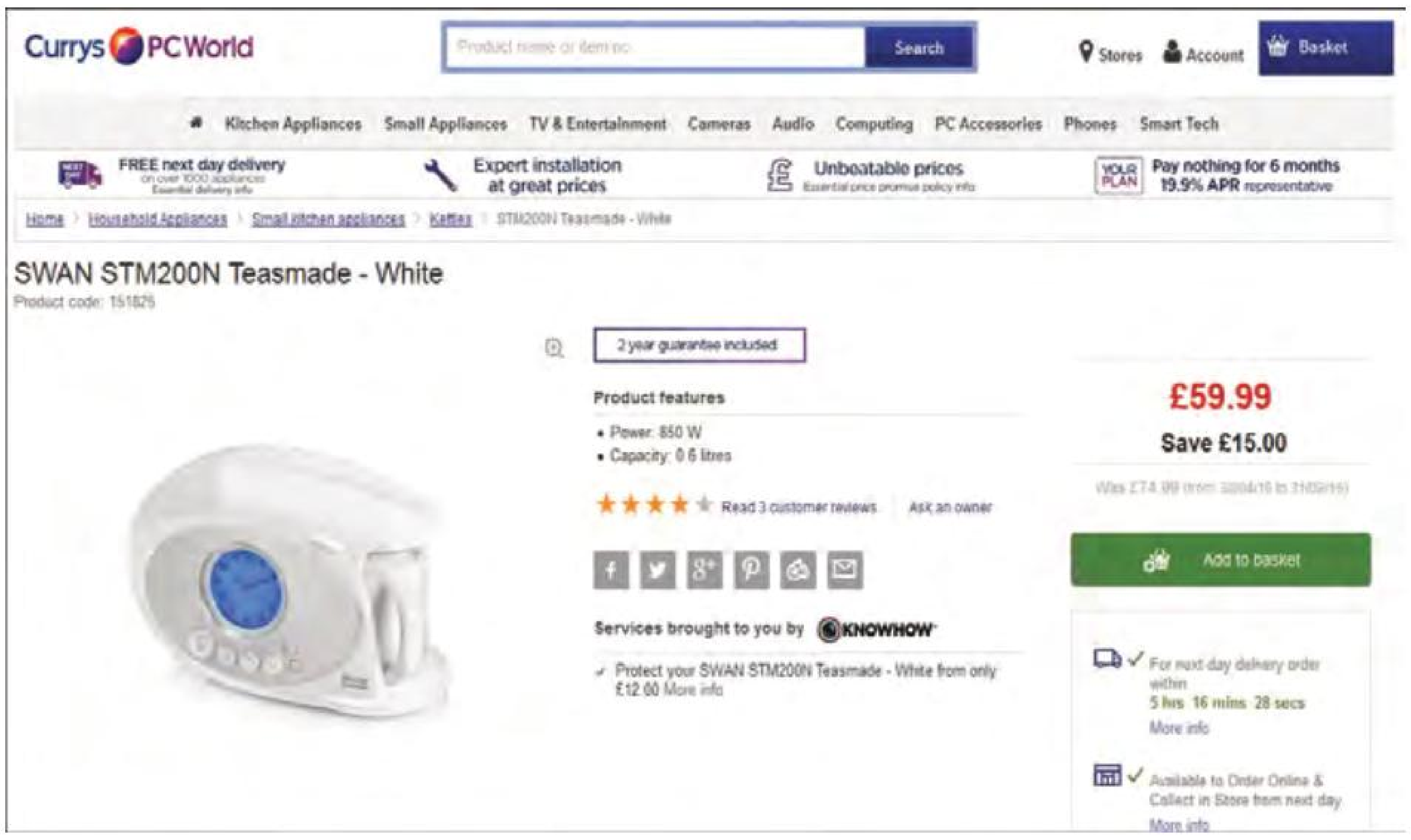
Arg-lost

When shopping around for a particular wristwatch – a semi-retirement present to myself – I was stunned by the inflated prices shown by some online jewellery stores. While surfing, some online ads from the retailer Argos for the same product caught my eye (those cookies again), touting the watch at a considerable saving. Just for once, the local store had the exact thing in stock, so a 'Fast Track' reservation was soon made, which enables customers to collect without queuing (as only the British do). However, no email order confirmation was received from Argos. Fortunately, a text message also arrived with that all-important Fast Track reference number, without which I would have been unable to prove that the goods were mine to collect. It's very wise to print off any web pages after checking out, just as a safeguard.

After checking my domain's mailserver logs it was found that the Argos mailserver IP had been blacklisted by an anti-spam filtering service – so even if the Argos email was sent, some customers would never receive their order confirmation anyway. I turned up to collect the watch and the store assistant duly handed it over, giggling that they could still trace the transaction if needed, provided I still had the SMS text message and Fast Track number. I never did get a Receipt and my Fast Track number is now engraved in stone, as befits my retirement present.

Full marks, I suppose, go to Argos for trying to win footfall by offering their stores as a collection point for eBay items. As customers will observe shelves holding a disparate collection of eBay parcels, often wrapped using admirable resourcefulness, as we scramble to make sense of 21st-century online shopping in a bricks-and-mortar world.

That's all for this month's *Net Work*. I'm grateful for readers for their continued interest, feedback and support and I wish everyone a very Happy Christmas – see you next year! The writer can be contacted by email: **info@epemag.net**.



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CIRCUIT SURGERY

REGULAR CLINIC

BY IAN BELL

Current mirrors for high-side current measurement

THE RETURN of *Ingenuity Unlimited* in the November 2016 issue of *EPE* was welcomed by regular *EPE Chat Zone* contributor ***bowden_p***, who also commented as follows on the high-side current measurement circuit contributed by Ken Wood (see Fig.1).

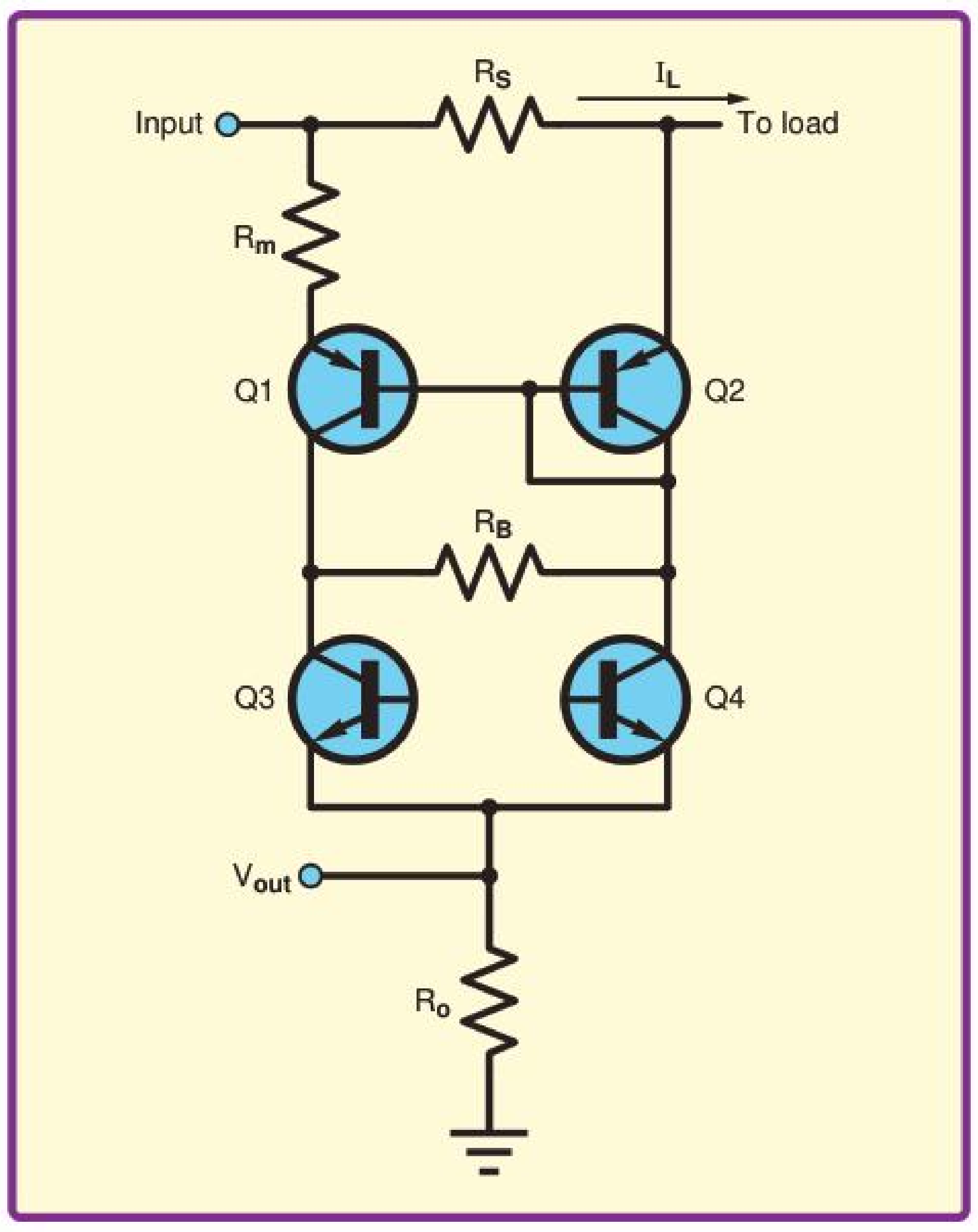

Fig.1. Ken Wood's high-side current monitor circuit

'Nice to see a new *Ingenuity Unlimited* article in November's issue of *EPE*. Well done to both Ken Wood and Chris Hinchcliffe for their submissions. With a background of work in the semiconductor industry, I liked Ken Wood's novel application of current mirroring. Looking for the three-transistor version of the basic mirror (Wilson mirror), I came across this variant [on the **electronics.stackexchange** website]. Very similar to Ken's solution. Just goes to show that when faced with the same problem, independent thought can devise a similar solution!'

Although this circuit is not particularly common, variants of it appear in a variety of places and we will take look at some of these.

The *Chat Zone* discussion moved on to consider the issue of how non-ideal mirror characteristics might affect this circuit and which matched transistor pair or array device might be most useful for implementing it. We will also take a brief look at these aspects of the high-side current-measurement circuit. Before that, however, we will look at the general idea of high-side current measurement.

Supply current measurement

Measuring supply current into a load is at first sight straightforward – a sensing resistor is inserted in the supply or ground line between the power supply and the load. The sense voltage (V_S) dropped across the sensing resistor (R_S) is used to measure the supply current (I_L):

$$I_L = V_S/R_S$$

Despite its basic simplicity, there are some potential difficulties with the design of the measurement of supply-current-measurement circuits, and the possibility of detrimental side effects on the system for which the supply current is being measured. A number of factors may need to be considered when designing supply-current-measurement circuits. These include, heating and power dissipation in the sense resistor, the effect of ground voltage offset or supply-voltage drop on the measured circuit, accuracy of the required current measurement, voltage output of power supply (high-voltage circuits may need different approaches) and the physical nature of the ground/chassis in the system.

The value of R_S is typically a fraction of an ohm, possibly only a few milliohms for systems consuming several amps. V_S typically has a value of tens of millivolts. The sense resistor dissipates power, P_S:

$$P_S = I^2R_S$$

Making R_S smaller reduces dissipation, but also makes measuring the consequently smaller V_S more difficult to do accurately. On the other hand, smaller dissipation will reduce self-heating in R_S, which may help accuracy. If the value of R_S is temperature dependent (which it usually will be) the value of R_S will be different for high and low supply currents and the reading will not be so accurate unless this is taken into account. R_S does not have to be a resistor; it could be a piece of wire or a PCB track (trace).

High-side or low-side design?

One of the key decisions when designing a supply current monitor is whether to use high-side or low-side current monitoring. High-side monitoring uses a sense resistor in the supply line, whereas low-side monitoring places it in the ground line. The basic configurations of these two types of supply measurement circuit are shown in Fig.2 and Fig.3.

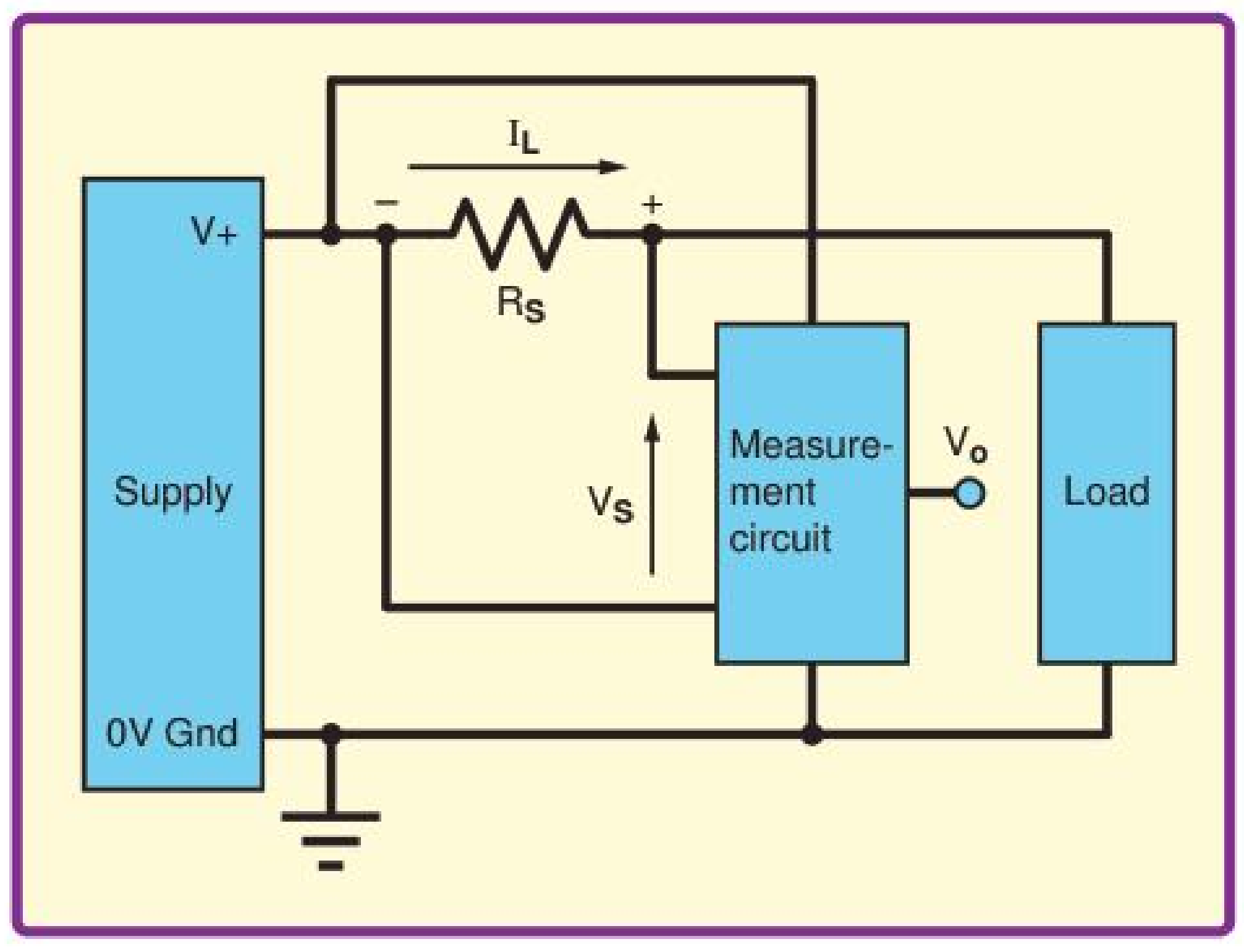

Fig.2. High-side supply current measurement: V_O *is proportional to* I_L

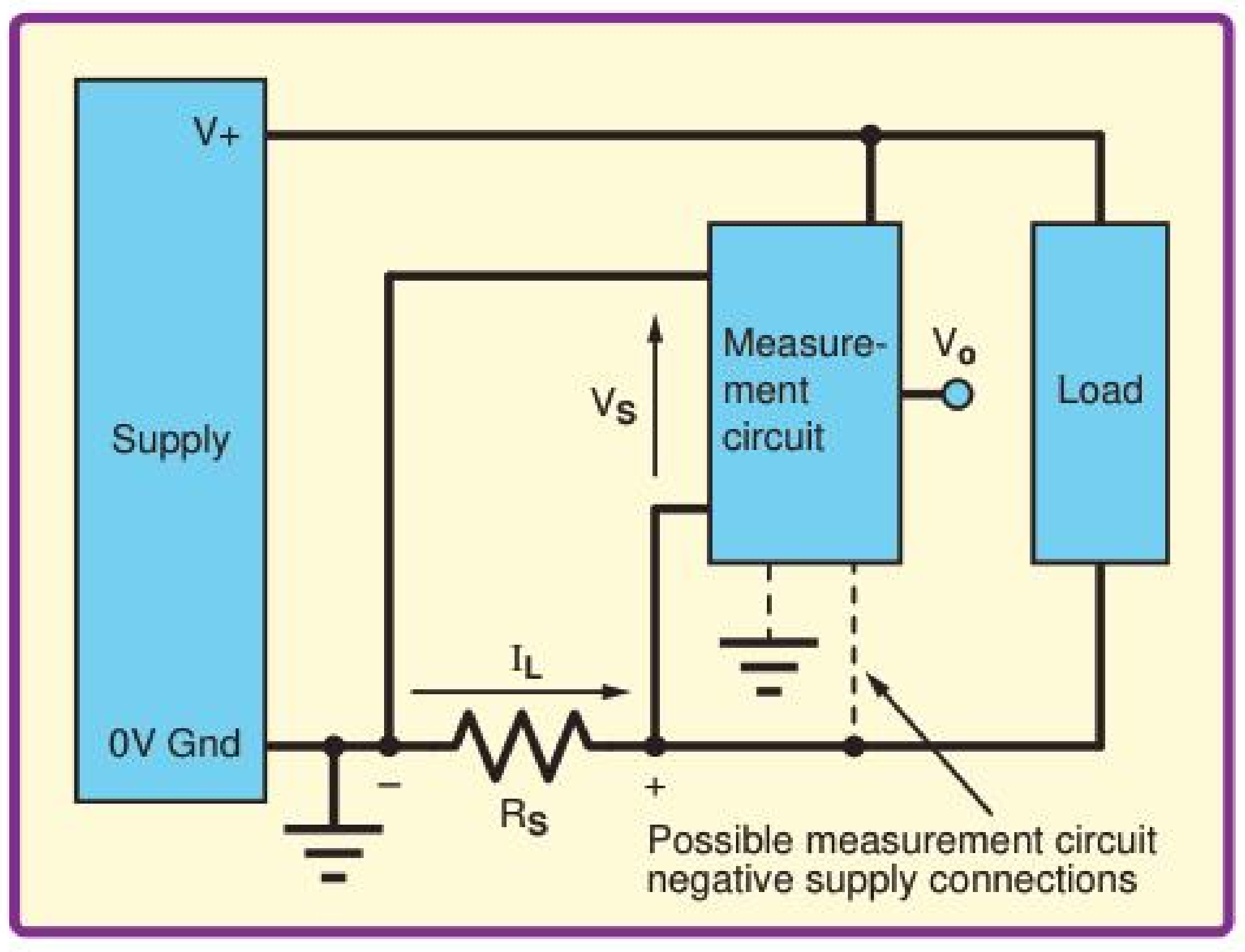

Fig.3. Low-side supply current measurement. V_O *is proportional to* I_L

In general, low-side circuits are easier to design. The sensing circuit sees V_S as a small positive voltage relative to the PSU's ground. This can be amplified for display on a meter or input to ADC. However, there is a serious problem with low-side monitoring, the circuit being measured will not have a true ground voltage. Any signal passed between this circuit and other circuitry connected to ground will be subject to an offset voltage equal to V_S. This may be intolerable in a system processing precision analogue signals. In situations such as automotive systems where components are grounded by their mechanical connection to the chassis, use of low side monitoring may be impossible. For these reasons, high-side monitoring is often preferred. Here we will also focus on high-side monitoring because it was the topic of the *Ingenuity Unlimited* article and subsequent discussion.

Differential amplifier

An op amp differential amplifier circuit could be used for both high-side and low-side measurement – an example high-side circuit is shown in Fig.4. The approach is particularly relevant to high-side monitoring because neither end of the sense resistor is grounded, which means a differential voltage must be measured (assuming a direct voltage measurement of V_S is to be used to obtain the value of I).

There are a couple of potential difficulties with the circuit in Fig.4. The input to the amplifier has a very large common-mode voltage (effectively the average of the voltages on the two sides of the sense resistor). Not all op amps will function correctly with large common-mode voltages (values close to their supply voltage), so careful choice is required. If the op amp's power supply connection is on the load side of the sense resistor (as indicated for one negative supply option in Fig.3) the input voltages will be outside the supply range by a small amount. Some devices can cope with this, but it cannot be assumed without checking the data sheet.

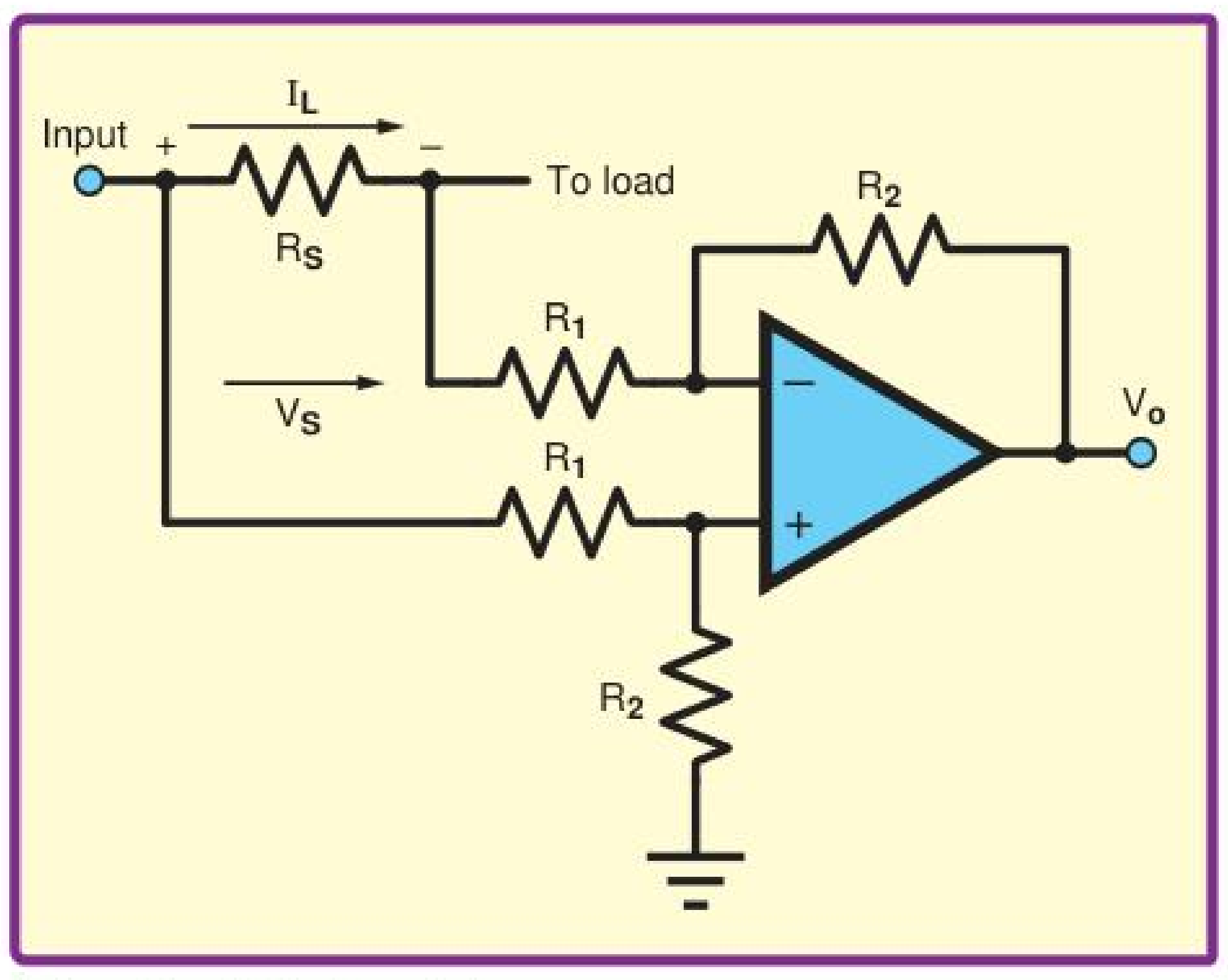

Fig.4. High-side current measurement using a differential amplifier

Another problem is that the differential amplifier circuit's common-mode rejection ratio (CMRR) is potentially very poor. More specifically, the CMRR of the circuit in Fig.4 is highly dependent on the accuracy of the resistors used – very close matching of resistor values is required to achieve good CMRR. If the CMMR is poor the supply voltage will influence the amplifier's output, reducing the measurement accuracy, particularly if the current is to be measured for variable supply voltage. Good differential amplifiers can be obtained using ICs with built-in factory-trimmed resistors.

High-side monitor

Use of a differential amplifier to measure V_S directly is not necessarily the best approach. A common alternative is shown in Fig.5. The circuit works as follows. We assume the op amp has very low input bias current, which we will ignore. With zero current into the inverting input the drop across R_2 is zero, so the inverting input is at the same voltage as the load. The feedback in the circuit controls the voltage difference between the op amp's inputs to be zero. Thus the op amp side of R_1 is at the load voltage (same as the inverting input). The other side of R_1 is at the input voltage, so the voltage across R_1 is equal to V_S, the voltage across the sense resistor. Thus, the current through R_1 is:

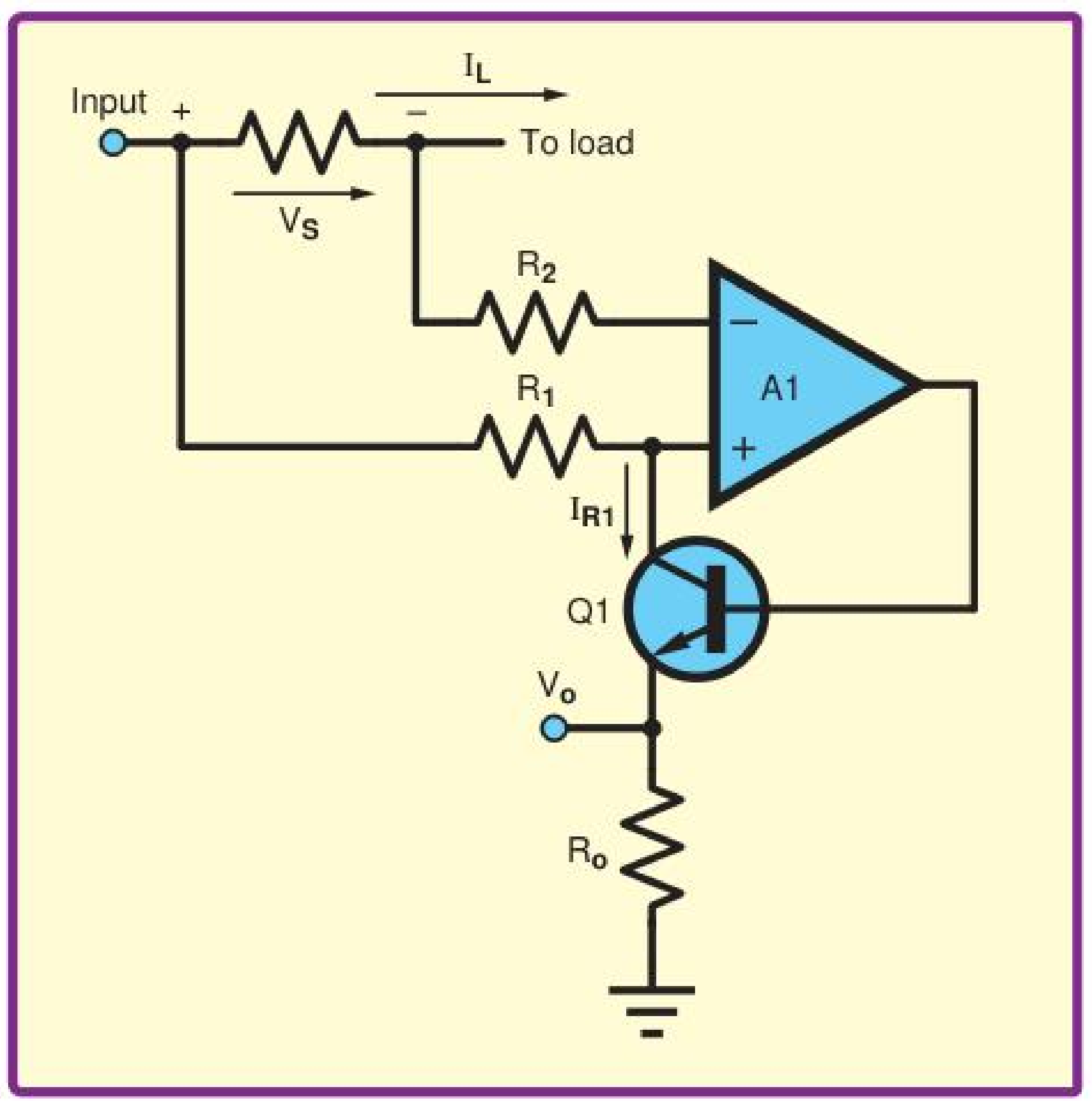

Fig.5. A common high-side current measurement circuit

$$I_{R1} = V_S / R_1$$

But we also know that V_S is given by:

$$V_S = R_S I_L$$

So

$$I_{R1} = \frac{R_S}{R_1} I_L$$

Given that R_S is small, and noting that R_1 can be much larger than R_S, the current used for measurement (I_{R1}) can be much less than the load current, which of course is essential for efficient operation, particularly for large load currents.

Ignoring the base current in Q_1, I_{R1} also flows through R_O to produce an output voltage, which is proportional to I_L

$$V_O = \frac{R_O R_S}{R_1} I_L$$

Feedback

To understand the feedback, consider an increase in load current. This will increase V_S, which will tend to increase the voltage difference between the op amp's inputs. This will tend to increase the output voltage, in turn increasing Q_1's collector current, which is equal to I_{R1} assuming than no current flows into the op amp's inputs. Increasing I_{R1} increases the voltage drop across R_1, which decreases the voltage difference across the op amp inputs. Thus, increasing I_L and hence V_S will cause I_{R1} to increase to maintain the op amp's input voltage difference at zero. Similarly, decreasing I_L will decrease I_{R1} to maintain the zero input difference.

The circuit in Fig.5 is available in IC form; for example, the INA139 and INA169 high-side measurement current shunt monitors from Texas Instruments. These operate from 2.7V to 40V (INA139) or 60V (INA169) and have supply pins for powering the chip which are independent of the connection to the supply being monitored (although they can be the same). In this case, R_1 and R_2 are on-chip 1kΩ resistors, and R_S and R_O are external. Another example is the MAX4172 low-cost, precision, high-side current-sense amplifier from Maxim Integrated, which replaces the R_O output resistor with a current mirror having a 1:50 ratio to provide a final output current of $50I_{R1}$ to pass through an external resistor.

The circuit in Fig.5, like that in Fig.4, requires an amplifier than can operate with both inputs at a voltage close to its supply voltage. This becomes difficult for large supply voltages, which may exceed the capabilities of most op amps. The circuit discussed in *Ingenuity Unlimited* (Fig.1) overcomes this by only requiring that the mirror transistors have sufficient voltage tolerance to deal with the monitored supply voltage.

The circuit in Fig.1 has some similarities with that in Fig.5 in terms of its basic principles of operation. In both cases the voltage across a 'measurement resistor' (R_m in Fig.1 and R_1 in Fig.5) is forced to be equal to the voltage across the sense resistor, R_S. In both cases the current in the measurement resistor is used to obtain a voltage across a grounded resistor, which is proportional to the load current. For the circuit in Fig.5, as just explained, this is achieved by the op amp feedback loop. For the circuit in Fig.1, the current mirror action forces the same current to flow in Q_1 and Q_2 and their base-emitter voltages to be equal (the transistors are matched), which when the loop via R_S, R_m $Q1_{BE}$ and $Q2_{BE}$ is considered implies the same voltage across R_S and R_m. Read the *Ingenuity Unlimited* article (*EPE*, November 2016) for a more detailed description of the circuit in Fig.1.

Multiple discovery

The comment made by ***bowden_p*** on the *Chat Zone* relating to finding a similar circuit on Electronics Stackexchange led me to look for other examples, although I would not claim to have made a particularly exhaustive search. The basic form of the circuit found by ***bowden_p*** is shown in Fig.6. It was posted by a user called ***Durgaprasad*** in 2013, but the discussion mainly concerned basic mirror operation. The circuit differs from Fig.1 in the use of separate emitter resistors in the NPN mirror and lacks the 'start up' resistor R_B. The same circuit is also found in a number of other locations, which are more relevant, so we shall discuss those.

The earliest example found was in United States patent US5210475 by David Juzswik and Bruce Wrenbeck of United Technologies Automotive (filed 1991, published 1993). The patent concerns high-side power monitoring in power control circuits such as H-bridge switches for a bidirectional loads. The patent includes schematics of five varients of the circuit, including

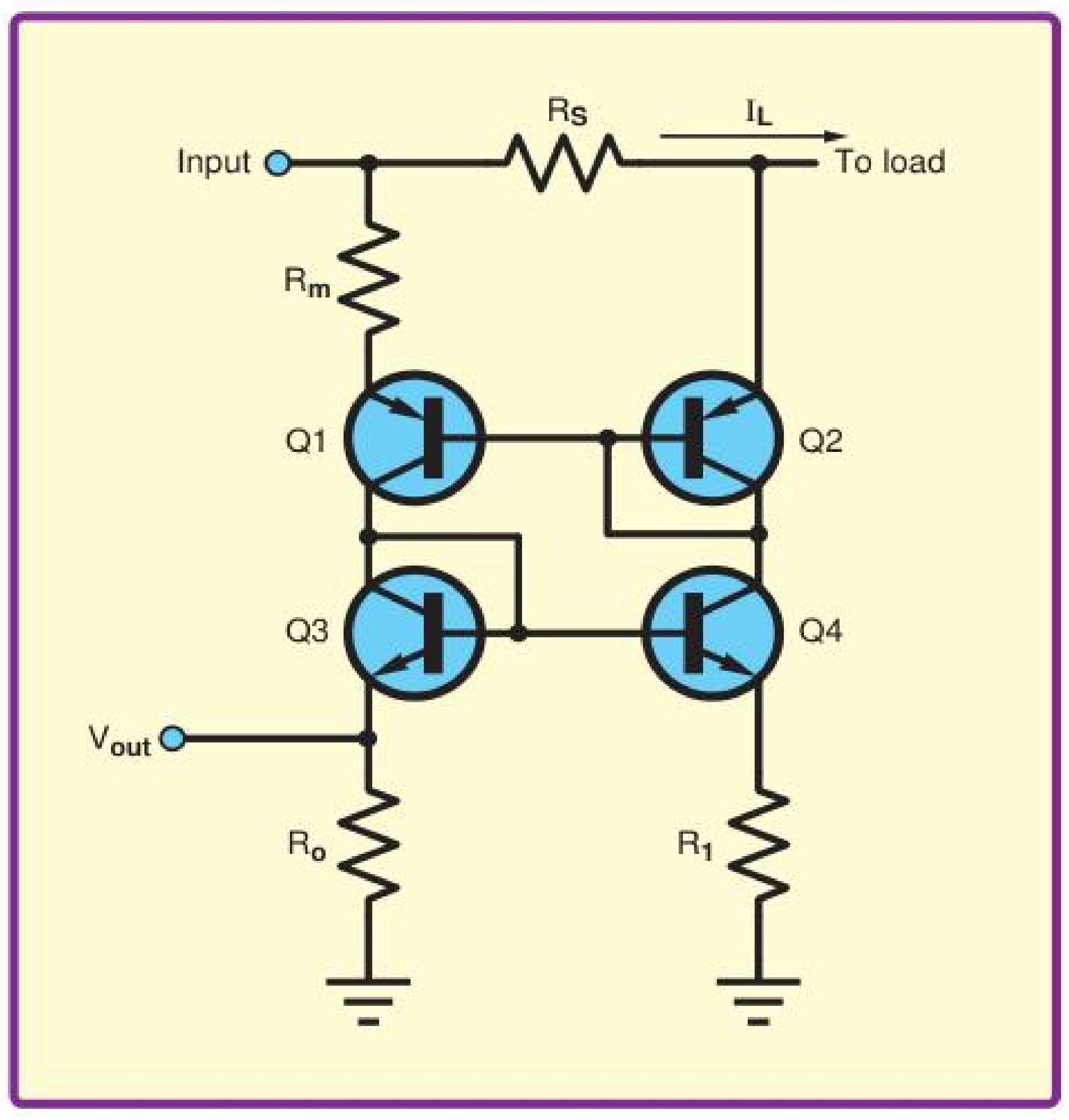

Fig.6. One variant of the current-mirror-based high-side monitor (this occurs in a number of places)

ones similar to Fig.1 and Fig.6. Resistor R_B from Fig.1 is not present. Another circuit places the output resistor between the mirrors and the other two circuits have additional transistors to improve performance.

The circuit in Fig.6 also occurs as a 'typical application circuit' in the datasheet of the Zetex ZDS1009 SM-8 complementary current mirror IC (see Fig.7). This chip basically contains the transistors required for the circuits in Fig.1 and Fig.6 – just add the resistors. Zetex give example values as R_S = 100mΩ and $R_m = R_1 = R_2$ = 100Ω (Fig.6) giving a sensitivity of 100mV/A.

Another document from a semiconductor manufacturer which includes the circuit in Fig.6 is an NXP product brochure titled *Simplify circuit design, save system costs*, which concerns devices such as matched transistors, current mirrors and differential pairs. The brochure features devices such as the BCV62 PNP general-purpose double transistor in the context of current mirror applications. The brochure also includes another variant of the high-side monitor circuit (see Fig.8) which uses a single mirror.

Op amp feedback

A high-side current monitor circuit designed by Bob Bell and Jim Hill of On Semiconductor is featured in the March 2001 issue of *EDN* magazine. The circuit uses a current-mirror arrangement like the circuits in Fig.1 and Fig.6, but also includes an op amp and transistor feedback loop like the circuit in Fig.5. A simplied version of the circuit is shown in Fig.9. For the full schematic, consult the original article, which is available online.

The current source sets up the operating current of the circuit and feedback ensures that the inputs to the op amp are at the same voltage, which keeps the voltages across equal resistors R_3 and R_4 the same, helping to ensure that the mirror currents are equal. The collector currents in Q_1 and Q_2 must be equal due to the mirror action, but the currents in R_1 and R_2 are not equal because of R_S and I_L. In order to balance the circuit, and keep the collector currents of Q_1 and Q_2 equal, I_3, which is the difference between I_1 and I_2 must by diverted via the MOSFET transistor and R_O.

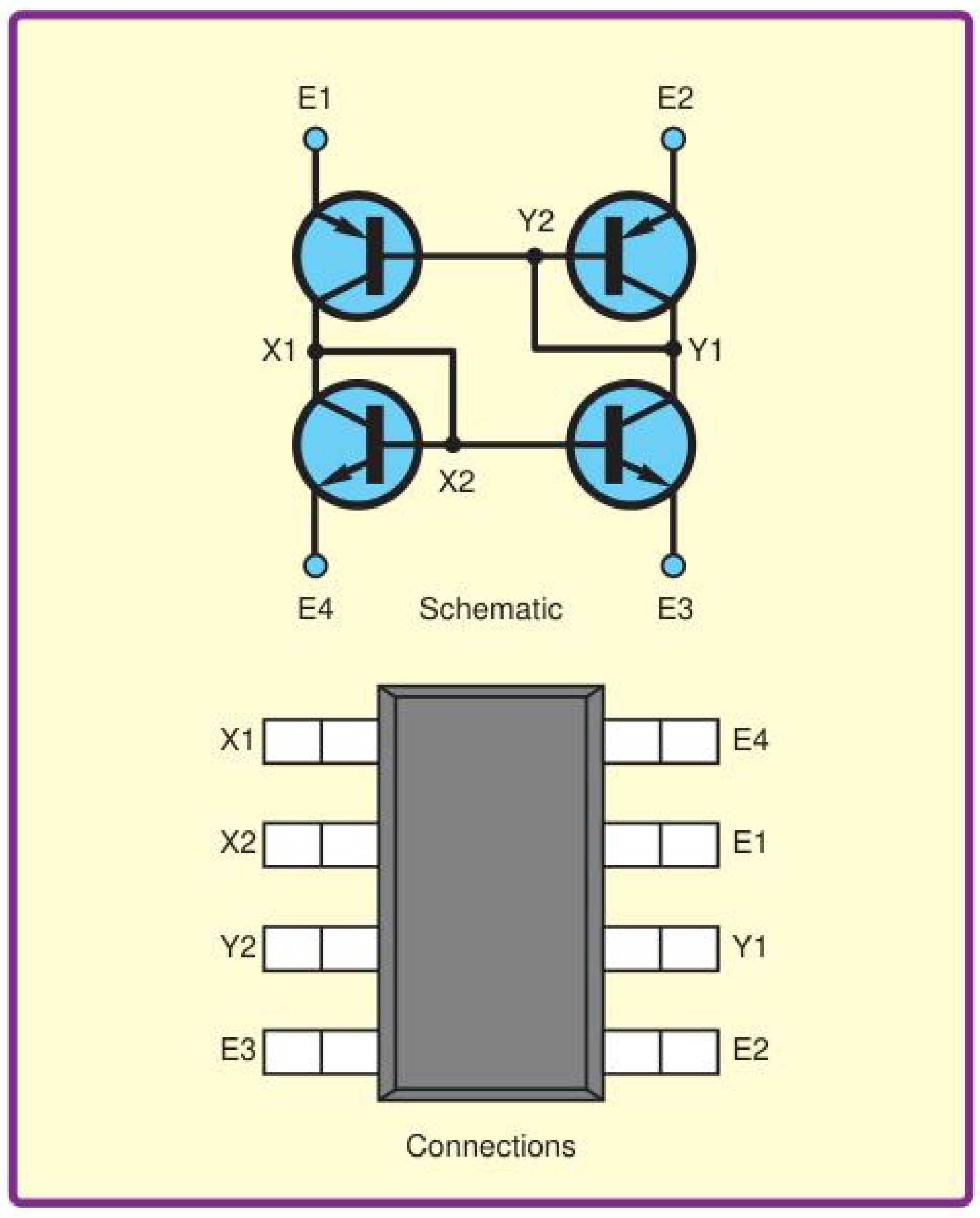

Fig.7. Zetex ZDS1009 SM-8 complementary current mirror (from Zetex data sheet)

We can analyse the circuit in Fig.9 by applying Kirchoff's Voltage Law around the loop formed by R_1, Q_1 and Q_2's base-emitter junctions, R_2 and R_S. The law states the voltages around a loop in a given direction sum to zero, so we have:

$$-(I_1 + I_3)R_1 - V_{BE1} + V_{BE2} + I_2R_2 + I_SR_S$$
$$+ I_SR_S = 0$$

But $R_1 = R_2$, and the base-emitter voltages are equal as they are part of matched pair in a current mirror, so we cancel some terms, leaving:

$$-I_3R_1 + I_SR_S = 0$$

From which we get:

$$I_3 = \frac{R_S}{R_1} I_s$$

This current flows through R_O to produce the output voltage V_O

$$V_O = \frac{R_O R_S}{R_1} I_S$$

Note that this is a relationship between I_S and V_O not I_L and V_O. I_S is dominated by I_L but includes the mirror current I_2. Unlike the others circuits, here the mirror current is fixed, it is set by the current source, so I_2 will cause a small fixed offset in the I_L to V_O relationship.

Better mirrors

Use of current mirrors for high-side current measurements is discussed in detail by George Mitev Mitev in a paper from 2009 in the *Annual Journal of Electronics*. This paper addresses one of the issues commented on in the *Chat Zone* discussion – that is the effect of current mirror quality on the accuracy of the measurement. The mirroring quality is affected by the inherent accuracy of the mirrors in copying currents, but more importantly in this case by the Early effect. The Early effect causes the current from the mirror to vary with the collector-emitter voltage of the transistor rather than remaining truly constant. We have discussed the Early effect in the context of current mirrors, see *Circuit Surgery* (May 2015).

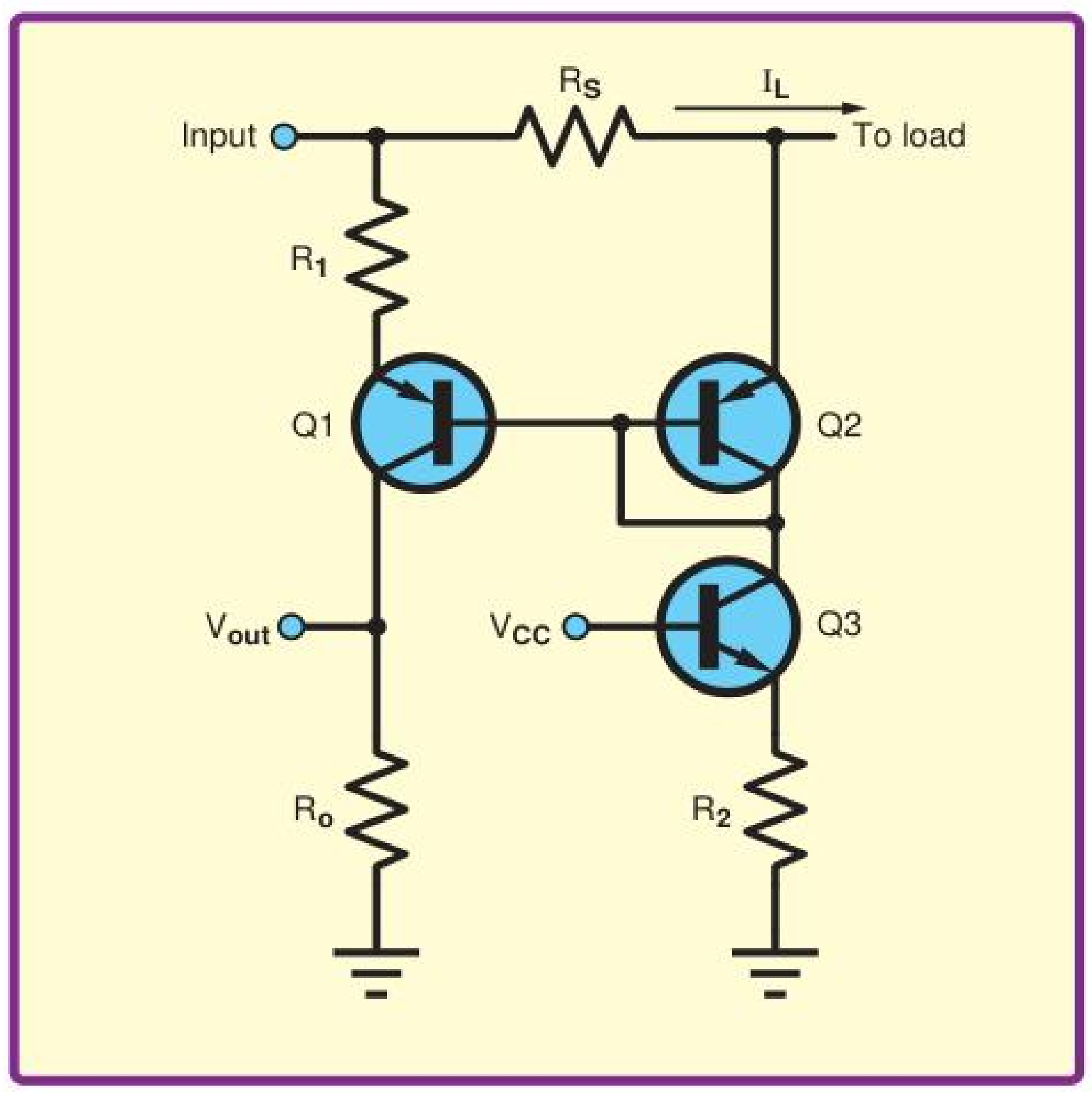

Fig.8. Another variant – this one is featured in an NXP product brochure

The impact of the Early effect on the current-mirror-based current monitors in Fig.1 and Fig.6 is to undermine the linearity of the measurement. The equations presented here, and in the *Ingenuity Unlimited* article, generally result in relationship between the sensing output voltage, V_O, and the load current, I_L of the form $V_O = KI_L$ where K is a constant set by the relevant resistor values. Unfortunately, in the circuit in Fig.1, K is not constant and varies with I_L. The simulations presented in the Mitev paper show that a circuit like that in Fig.6 could be used for a three-decade range of current measurement (eg, 10µA to 10mA) but K was only constant for a relatively small range of current variation (one decade: 1 to 10mA in the example presented).

The circuit in Fig.10 uses two four-transistor Wilson current mirrors to achieve far better linearity than the

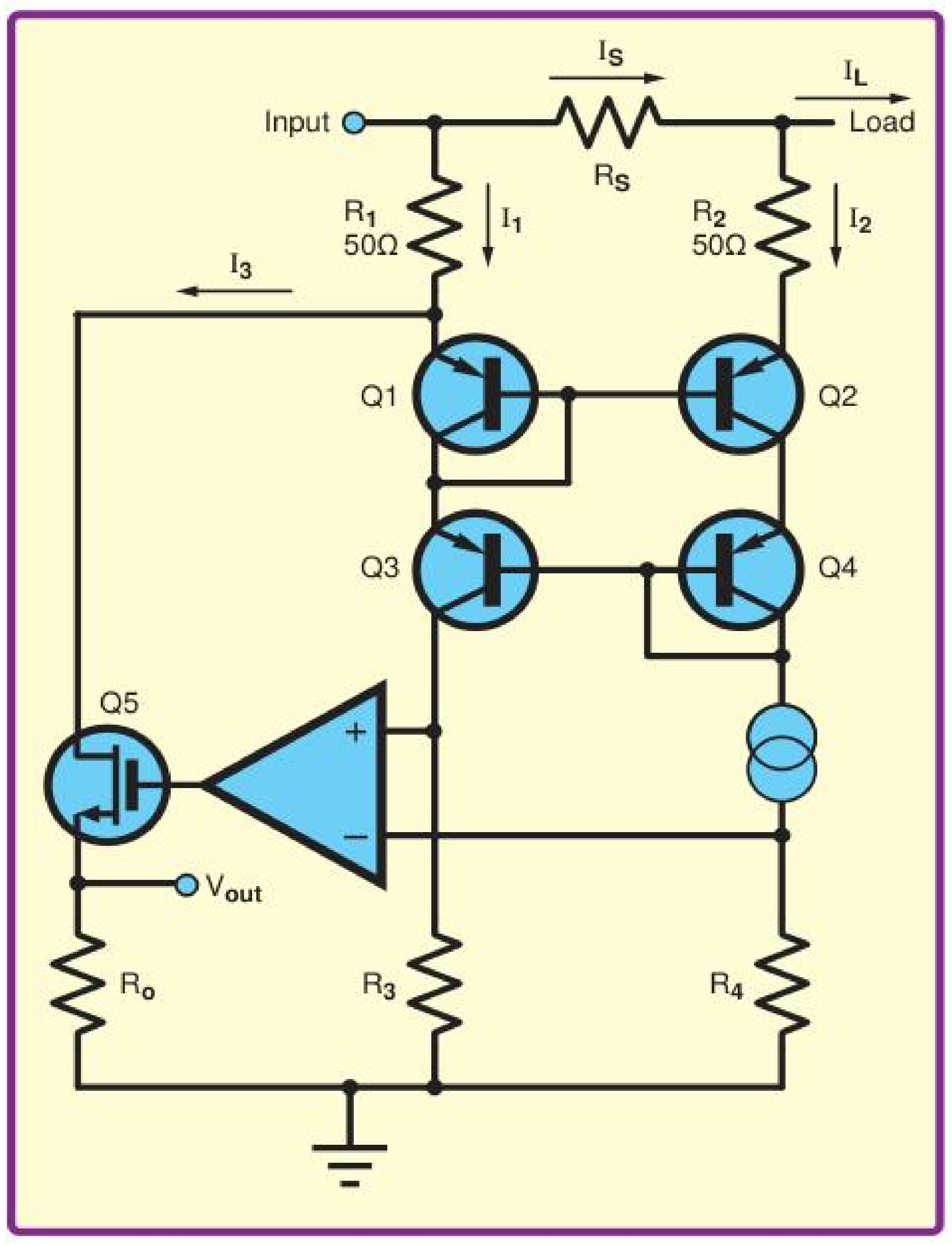

*Fig.9. Simplified version of the high-side current-sense circuit by Bob Bell and Jim Hill (*EDN*, March 2001)*

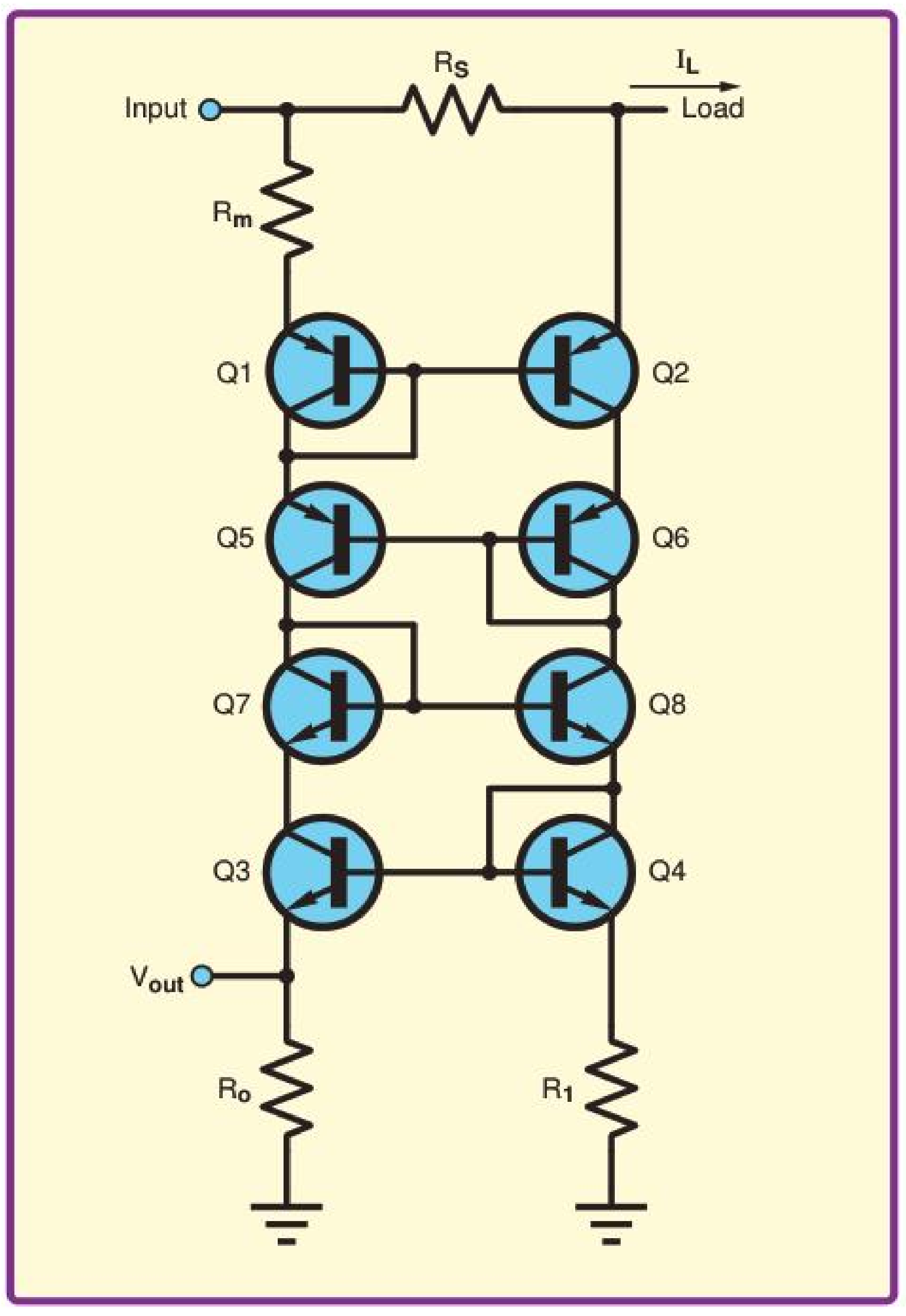

Fig.10. One of the circuits analysed by George Mitev Mitev in his paper on high-side current monitors

circuit in Fig.6. Mitev's simulations show this circuit, configured for the same current range, was very linear over two decades (100µA to 10mA) and was much better over the full three decade 10µA to 10mA than the circuit in Fig.6. Whether or not the additional complexity of the circuit in Fig.10 is worthwhile will depend on how accurate a current measurement is required and the range of current variation that is expected. If, for example, the currently monitor is only used to detect overcurrent conditions, via a threshold switch, then the simpler circuit would be sufficient.

Matched transistors

As discussed on the *Chat Zone*, current mirrors rely on the transistors used being closely matched, both in terms of their characteristics and thermally. Semiconductors are very sensitive to temperature, so the transistors in a current mirror must be thermally linked so that they remain at the same temperature at all times. For this reason, matched-transistor multi-transistor devices, such as the Zetex ZDS1009 and BCV62 mentioned above should be used. It is difficult to guarantee thermal equilibrium for discrete devices, even if their characteristics are matched, although it can be done by mounting the devices close together on a heatsink.

There are many more matched multi-transistor products on the market, which may be suitable for current-mirror-based circuit designs. In construction terms, they vary according to whether or not they contain individual transistors cut from the same fabrication wafer (to ensure matched characteristics) or if the transistors are on the same substrate (referred to as 'monolithic'). In the latter case, care may be needed to connect the substrate to the most negative or positive point in the circuit, which will be noted in the datasheet, but which can restrict some applications. However, monolithic transistor arrays should provide better thermal matching than individual matched transistors in the same package. Devices featuring dielectrically isolated transistors on a common monolithic substrate, but which should not interact electrically via the substrate, are also available.

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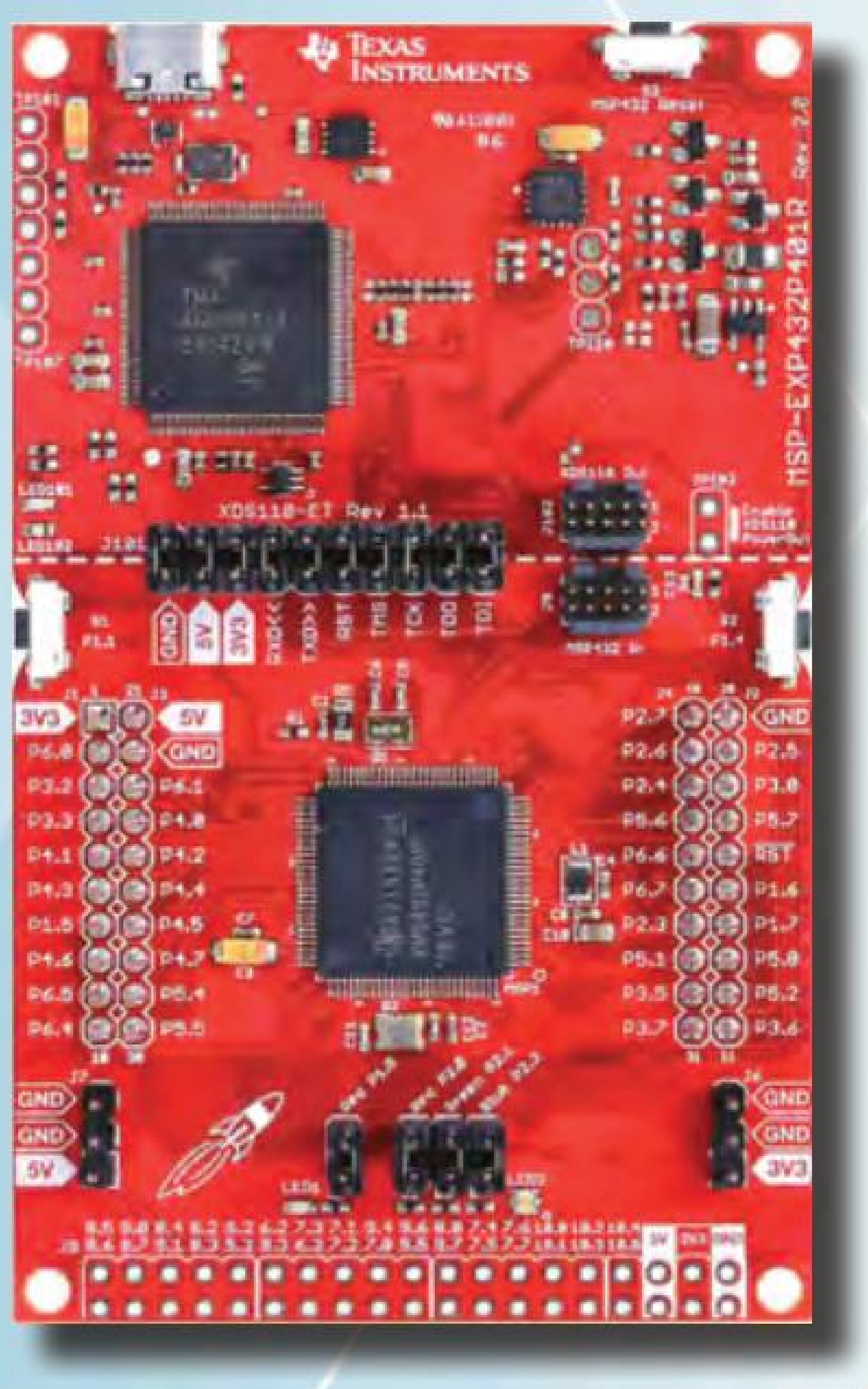

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PIC n' Mix

Mike O'Keeffe

Our periodic column for PIC programming enlightenment

PICs and the PICkit 3: A beginner's guide – Part 8

SO FAR in this beginner's guide, we've covered a lot of the basic PIC concepts, including GPIO control, ADCs and debounce, as well as some software control. This month, we get to sink our teeth into a very juicy topic: pulse-width modulation, or PWM for short.

Before moving on, I recommend having a read of the previous articles in the series. It's not strictly necessary for this article, but by referring back you will gain a greater insight into PICs and what we're trying to achieve here. You will also need the following software and hardware:

1. Purchase the PICkit 3 Low Pin Count Demo Board (**http://tinyurl.com/h2jj2ek**)
2. Purchase the PICkit 3 Programmer + USB Cable (**http://tinyurl.com/zcpx3le**)
4. Download *PICkit 3 Starter Kit User's Guide* (**http://tinyurl.com/jyqfeuk**)
5. Download MPLAB X IDE (**http://tinyurl.com/hmehqja**)
6. Download XC8 Compiler (**http://tinyurl.com/h5g9k5l**)
7. Download Example code for PICKit3 Starter Kit (**http://tinyurl.com/z2dm5k3**)

PWM – the basics

What exactly is PWM? In a PIC, PWM is the rapid and repeated switching of a GPIO (also known as an input/output port). Software is used to change the width of the GPIO's pulses and by changing the width of the pulses, the PIC effectively alters the *average* voltage at an output. There's a number of interesting things that can be done with this function. PWM is commonly used to dim LEDs, control the speed of motors and fans and even produce noise on speakers or buzzers.

Let's consider controlling the brightness of an LED. A simple way to do this would be to use an NPN transistor to vary the current from a fixed voltage using the circuit in Fig.1. Apply 5V to the transistor's base and the transistor is driven fully on. You'll get about 4.3V at the emitter and for a typical red LED, lose about 1.8V to forward voltage drop. That leaves 2.5V across the current-limiting resistor. Let's opt for a 10mA maximum current and we end up with a 250Ω resistor. Now, to dim the LED, all we have to do is reduce the voltage at the base. Between a base voltage of around 0.7V and 5V we have an infinite choice of voltages giving an infinite number of LED brightness levels, all done with a couple of components. What could be easier?

Now, the elephant in the room for this design is that it is an analogue approach, and a PIC is decidedly digital. True enough, it has analogue-to-digital converters (ADC) for inputs, which are very handy for measuring the outside world, but there are no digital-to-analogue converter (DAC) pins on the PIC16F1829. In the LED example, if a DAC were available then a designer might use it to drive the transistor's base – but there isn't one, so how can a PIC dim an LED? The way PIC designers have got around this problem is PWM. So, instead of applying 2.85V for roughly half the brightness the LED is switched on for only half the time. Now, if the LED was switched on and off every second then it would technically be true that only half the number of photons were emerging, but it would be a pretty poor version of a dimmed LED. The trick (for human eyes) is to switch on and off so fast that our eye-brain combo ignores any flicker and we see only the average brightness. This goes to the heart of PWM – the system being driven, whether it is an LED viewed by an eye or a DC motor's stator coil must be relatively slow in its response to fast switching. Slow enough to only 'see' the average of the applied pulses.

An important corollary of this is that a PIC user needs a reasonably good understanding of what a PWM output is driving to use this technique effectively. In the LED example the key parameter is the response time of a viewer. For most people, an LED switched at 60Hz will appear to be reasonably flicker free. For a motor control system it is the inductive time constant of the motor's windings. Another way to view this effect is to see the driven system as a low-pass filter that ignores the high-frequency switching and just sees the average DC component of the signal.

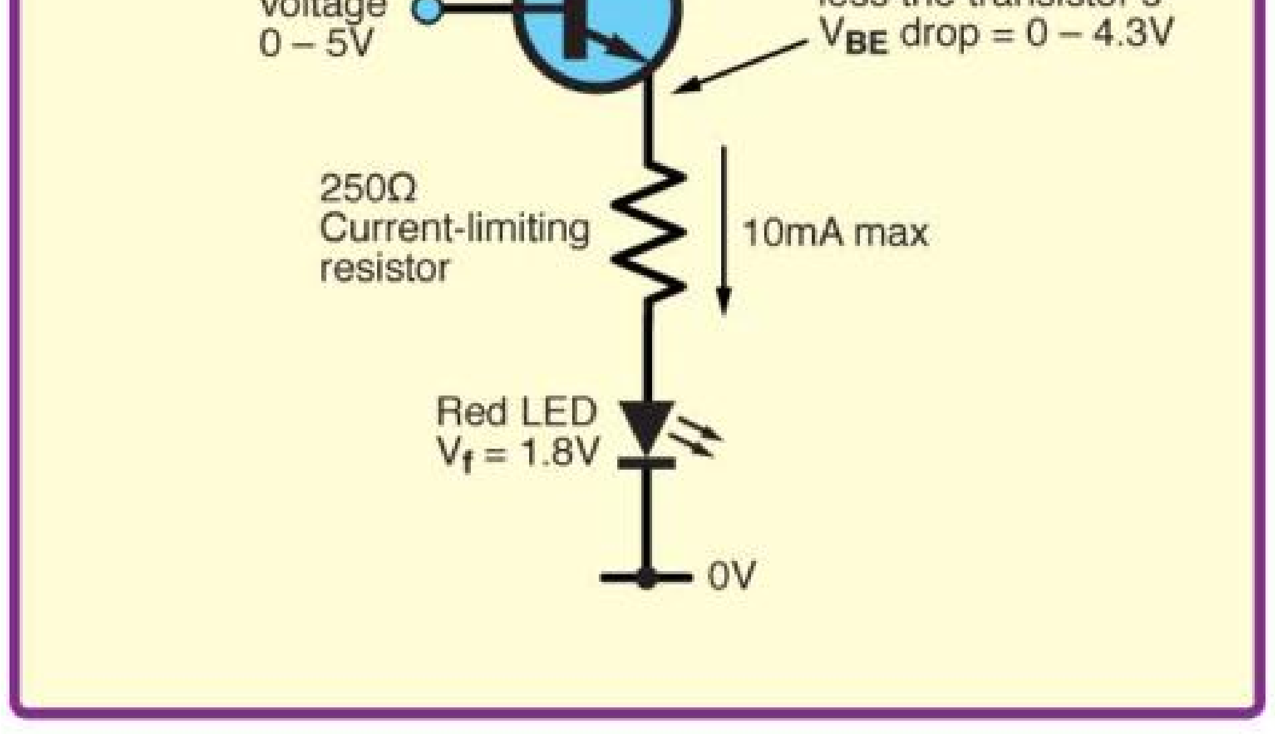
5V
Control voltage 0 – 5V
Control voltage less the transistor's V_{BE} drop = 0 – 4.3V
250Ω Current-limiting resistor
10mA max
Red LED V_f = 1.8V
0V

Fig.1. Simple analogue circuit to control an LED's brightness

To summarise, the PIC only ever outputs digital pulses, but with careful design and the right software a system can be fooled into thinking it is seeing a varying analogue signal – you could think of this as 'pseudo-analogue'. When designing a PWM system, the devil is in the pulse detail, and we need to consider four main parameters

- Period
- Pulse-width
- Pulse-width resolution
- Duty cycle

Period is the duration of one complete cycle, or the total amount of 'on' plus 'off' time. This sets the overall frequency of operation. Its upper limit is set by the PIC's clock frequency. The higher the frequency, the more effectively – as seen by the driven system – we can control the power output.

Next, pulse-width is the length of time that power is on. This dictates the percentage of time power is supplied.

The pulse-width is variable, but this is a digital system, not an analogue one, so the variability of the pulse width is not infinite, but is defined by a number of 'steps'. Resolution is the maximum number of steps that can be present in the pulse-width, giving our 0% to 100% range; the higher the resolution, the more precise the control. For example, if the resolution is 10 bits (the maximum allowed) then the pulse width can be varied over 10^{10} = 1024 different values from fully off all the time, to fully on all the time. It is important to note that this is still just one pulse – steps are not individual pulses, but division units of a single pulse's width.

Closely related to pulse width is 'duty cycle', which is the percentage of time that the device is on compared to the time for a whole cycle – ie, it is the pulse width divided by the period.

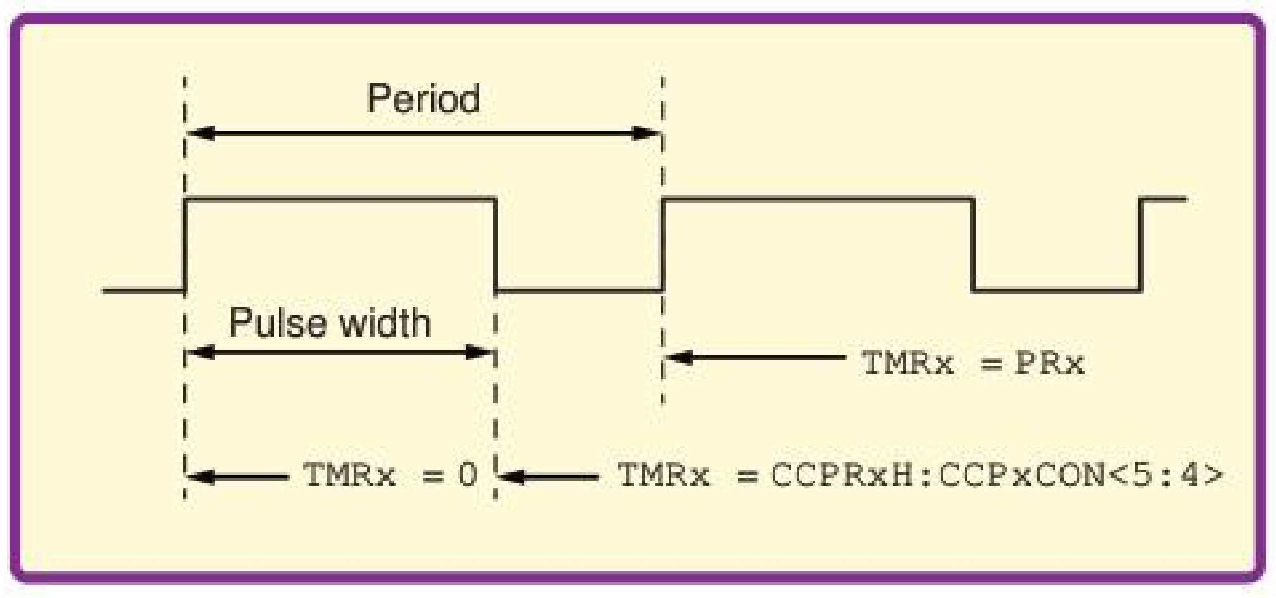

Fig.2. CCP PWM Output Signal

Fig.2 illustrates these relationships. We can see that the period is the time between the rising edge of one pulse and the rising edge of the next pulse. The period value is stored in `PRx`. `TMRx` represents the value in the timer, which starts at time = 0. `CCPRxH:CCPxCON<5:4>` is the read-only register for the two least-significant bits of the duty cycle. The other eight most-significant bits are in `CCPRxL`.

For more in-depth details of the workings of the PWM, it's a good idea to look at the datasheet for the PIC16F1829: **http://ww1.microchip.com/downloads/en/DeviceDoc/41440A.pdf**
The datasheet gives a step-by-step guide to starting the PWM on page 223.

PWM inside the PIC16F1829

It might seem like a trivial task, adjusting the PWM to simply change the output to a high or low at various times to get the value needed. However, inside the PIC it isn't quite as simple as that. PWM is *indirectly* controlled by the core processor in the PIC. The heavy lifting is performed by a standalone sub-system called the Capture/Compare/PWM module (CCP for short), which is a peripheral that allows the user to time and control different events. In Capture mode, the peripheral can time the duration of an event. The Compare mode allows the user to trigger an external event after a specified time has passed. Then there's the PWM mode, which generates the modulated pulse width.

For PWM to operate, the PIC uses all features of the Capture/Compare/PWM to provide the PWM output. The period is stored in the `PR2` register, and the duty cycle is stored in the `DC2B` register. Once the timer has been activated, the PWM will operate as it has been instructed to do. At the rising edge of the timer after it is initialised, the PWM is output as a high. The PWM module takes the duty cycle value, the period and the clock speed and calculates what the pulse width should be. Then with every clock tick, the comparator captures the time, compares it to the period and duty cycle and if the measured pulse width is equal to the calculated pulse width time, then the signal is set low. The timer runs the output low until the period time is met and the cycle repeats.

This module is quite separate to the microprocessor inside the PIC. At the start of this series I discussed the differences between microcontrollers and microprocessors, and it's peripherals like the CCP, which make these microcontrollers so powerful. Since the CCP module is a separate system, all we have to do is set some registers and then enable it. It will then run without interrupting the microcontroller's behaviour. That means, once we set it up, we can do whatever we like in the code and we won't interrupt the main code flow or get interrupted by this module, unless we want to.

Actually, that's not entirely true! In theory, we could output a PWM signal on any general-purpose output pin, but we would have to do it 'manually', which means the PIC would spend all its time controlling this pin and wouldn't be able to perform any other tasks. Now you can see how powerful a separate independent module is. However, because it is a separate module, only special pins/ports can use this function. In the PIC16F1829, these ports are Port A2, A5, C3, C5 and C6. Last, do note that there are four separate PWM modules inside the PIC: CCP1, CCP2, CCP3 and CCP4.

LED dimming

Lesson 8 in the *PICKit 3 Starter Kit User's Guide* works through an example of taking an ADC value from the rotating potentiometer to adjust the brightness of an LED. The example is straightforward enough and accurately demonstrates how PWM can be used to dim the brightness of a LED. No components need to be added to the demo board to get this to work, but we do need to examine the software that does this. Let's take a look at the code for this lesson. Fig.3 shows a flowchart of the code. Each block breaks down the code into bite-size pieces. The PICKit 3 starter kit code can be downloaded from the link for item 7 in the list at the beginning of this article.

```
OSCCON = 0b00111000;
TRISC = 0;
LATC = 0;
```

It's important to set the internal clock speed for this application because this is how we define the period and duty cycle. `OSCCON` here sets the clock speed to 500kHz. This is followed by setting port C to outputs (`TRISC`) and latching a low output using `LATC`.

```
TRISAbits.TRISA4 = 1;
ANSELAbits.ANSA4 = 1;
ADCON0 = 0b00001101;
ADCON1 = 0b00010000;
```

The code above sets up the input port A4 for the input from the potentiometer and enables the ADC module. The first line sets the `TRIS` port as an input, then selects port A4 as an analog input. `ADCON0` selects A4 as the source for the ADC, enables the ADC module, while `ADCON1` sets up the ADC output parameter, left justified, its speed and the voltage reference. (These ideas were covered in *PICKit 3 Starter Kit User's Guide, Lesson 4: Analog-to-Digital Conversions*.)

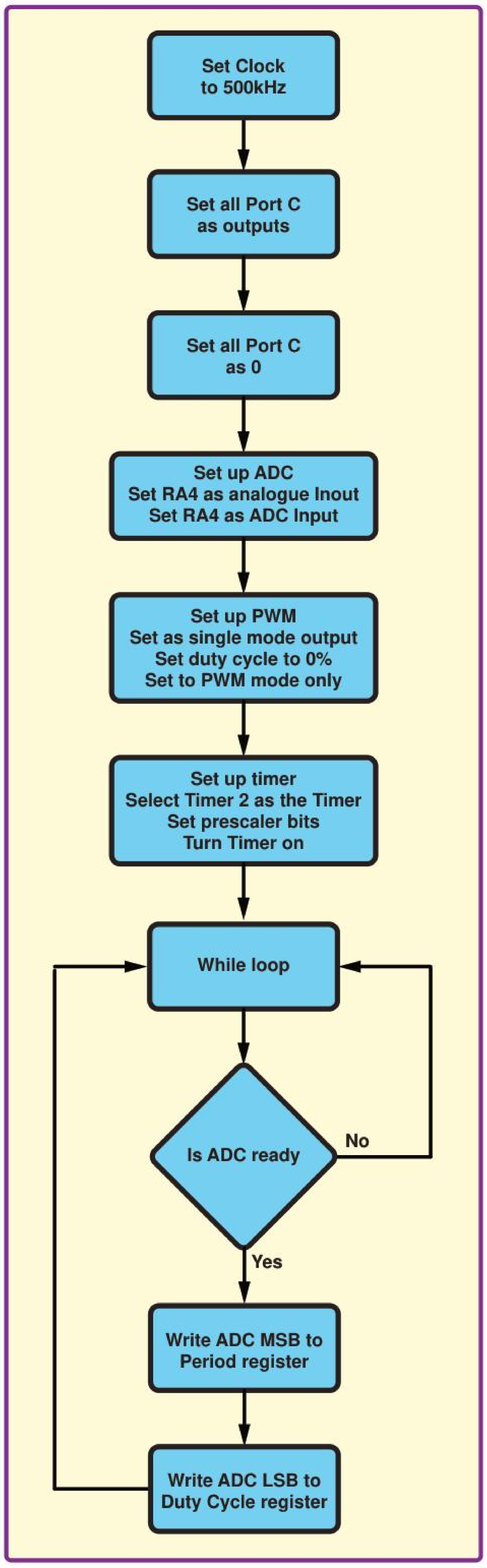

Fig.3. Flow Chart for PIC PWM Code

```
CCP2CON = 0b00001100;
PR2 = 255;
```

This piece of code sets up the PWM module by setting the period and duty cycle. The `CCP2CON` register is the control register for the PIC's Capture/Compare/PWM module. If you refer to the PIC16F1829 datasheet (page 240), you'll notice that bits 7 and 6 set single mode output (00), bits 5 and 4 set the starting duty cycle (00, 0% in this case), bits 3, 2, 1, 0 then set the module to PWM mode only (1100). Moving on to the next line, `PR2` is the Timer2 Period register. I'm not going to say much about timers here as it has a full lesson next month. We set this to the maximum value for the period, which is 0xFF (hex) or 255 (decimal) bits.

```
CCPTMRSbits.C2TSEL = 0b00;
T2CONbits.T2CKPS = 0b00;
T2CONbits.TMR2ON = 1;
```

For the PWM module to work, we need to allocate it a timer so that we can compare the time compared to the calculated pulse-width. The timer is another separate module that can be used to provide a clock signal for other modules. In this case, we set C2TSEL, the CCP2 Timer selection bits in the CCPTMRS PWM timer selection control register to base the CCP2 timer from Timer2.

Then we set what's known as a prescaler in the Timer2 Clock Prescale select bits to 1:1. The prescaler allows timing events to be scaled to give much larger pulse widths, while maintaining resolution. Here, we use a 1:1 ratio, so the pulse-width is based off the same time as Timer2. This is explained in greater detail next month in Timers. Then we enable the PWM module itself by enabling the Timer2 by setting the register for TMR2ON.

```
while (1) {
        __delay_us(5);
        GO = 1;
        while (GO) continue;
        CCPR2L = ADRESH;
        CCP2CONbits.DC2B = (ADRESL>>6);
}
```

The main `while loop` is nothing we haven't seen before. There's a delay, we see the GO bit for capturing an ADC value. We wait until the GO bit is cleared to indicate the ADC is ready, then we store that 10-bit value in the Timer2 control register (CCPR2L) and in the PWM duty cycle bits – DC2B.

Some maths

In this example, the duty cycle and pulse-width are automatically calculated for us. However, you may want to specify exact values for these. Using the values from the code above, we can calculate the period, pulse width and duty cycle. To do this we use the following equations:

$$\text{PWM Period} = (\text{PRx} + 1) \times 4 \times \text{Tosc} \times (\text{TMRx Prescale Value})$$

Note: $\text{Tosc} = 1/\text{Fosc}$

We can calculate the period by taking all the values from the code above; $\text{PRx} = 255$, $\text{Fosc} = 500{,}000$.

$$\text{PWM Period} = [(255) + 1] \times 4 \times (1/500{,}000) \times (1) = 0.002048\text{s (seconds)}$$

Tosc is the period of the internal oscillator and we set this value earlier in the OSCCON register. If this register is changed, then the PWM frequency, period and pulse width would be altered automatically. Period is the reciprocal of frequency, so:

$$\text{Frequency} = 1 / (\text{PWM Period}) = 488.28125\text{Hz}$$

The pulse width can be calculated with the following equation:

$$\text{Pulse width} = (\text{CCPRxL:CCPxCON<5:4>1}) \times \text{Tosc} \times (\text{TMRx Prescale Value})$$

CCPxCON<5:4> can also be referred to as DCxB, which is the PWM duty cycle least-significant bits, where CCPRxL:CCPxCON<5:4> refers to the whole 10 bits of the duty cycle. To get a duty cycle of 50%, we multiply 1024 (10 bits) by 50/100, giving us 512. As can be seen from the equation above, the pulse width is exactly half of the calculated PWM period. The TMRx Prescale Value was chosen to be 1:1, so the value here is 1. Substituting these values into the equation we get:

$$\text{Pulse Width} = (512) \times (1/500{,}000) \times 1 = 0.001024\text{s}$$

Did you notice?

An interesting point to note in the code above is that we don't actually choose which pin we want the PWM to operate on. If we look at the datasheet for the PIC16F1829, we can see that CCP1 operates on port C5, CCP2 operates on ports A5 and C3, CCP3 operates on port A2 and CCP4 operates on port C6. If we use CCP1, CCP3 or even CCP4, then it's very clear which port we're using as an output. However, in the lesson above, CCP2 is used and it isn't defined whether we use A5 or C3.

If you compile and run the code, it can be clearly seen that the DS4 LED illuminates and dims. This LED is connected to port C3, so C3 must be the default. If we want to use port A5 instead, then we would need the following command:

```
APFCON1BITS.CCP2SEL = 1;
```

This command selects between port C3 and A5 for the CCP2 module. In fact, for the purpose of completeness, the code should really have the following line of code to ensure port C3 is selected. It isn't strictly necessary, but it is good practice.

```
APFCON1BITS.CCP2SEL = 0;
```

Advanced features

I've only touched on some of the *basic* features of PWM here; we haven't even looked at motor control using PWM bridges, but we need to take this topic slowly – it is complicated! I will return to look at the more advanced aspects of PWM control in a later column

Next month

In *PIC n' Mix* next month we'll cover a topic that is linked closely with PWMs – timers. These allow us to perform all sorts of operations, from keeping time to inserting delays and waking from sleep modes. Timers have a heavy influence on PIC behaviour and how fast it operates, so next month is important!

Not all of Mike's technology tinkering and discussion makes it to print.

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By Robert Penfold

INTERFACE

Frequency measurement and a first look at the BBC Micro Bit

THE SUBJECT of timing using a Raspberry Pi has been covered in recent *Interface* articles, and this month we move on to the associated subject of frequency measurement. The conventional approach to frequency measurement using a digital circuit is to count pulses. With this system, the frequency is determined by counting the number of input cycles in a certain period of time. In practice, this tends to be rather more complex than it sounds, and usually involves a fair amount of hardware. In a somewhat simplified fashion, the block diagram of Fig.1 outlines the arrangement used for a pulse-counting digital frequency meter.

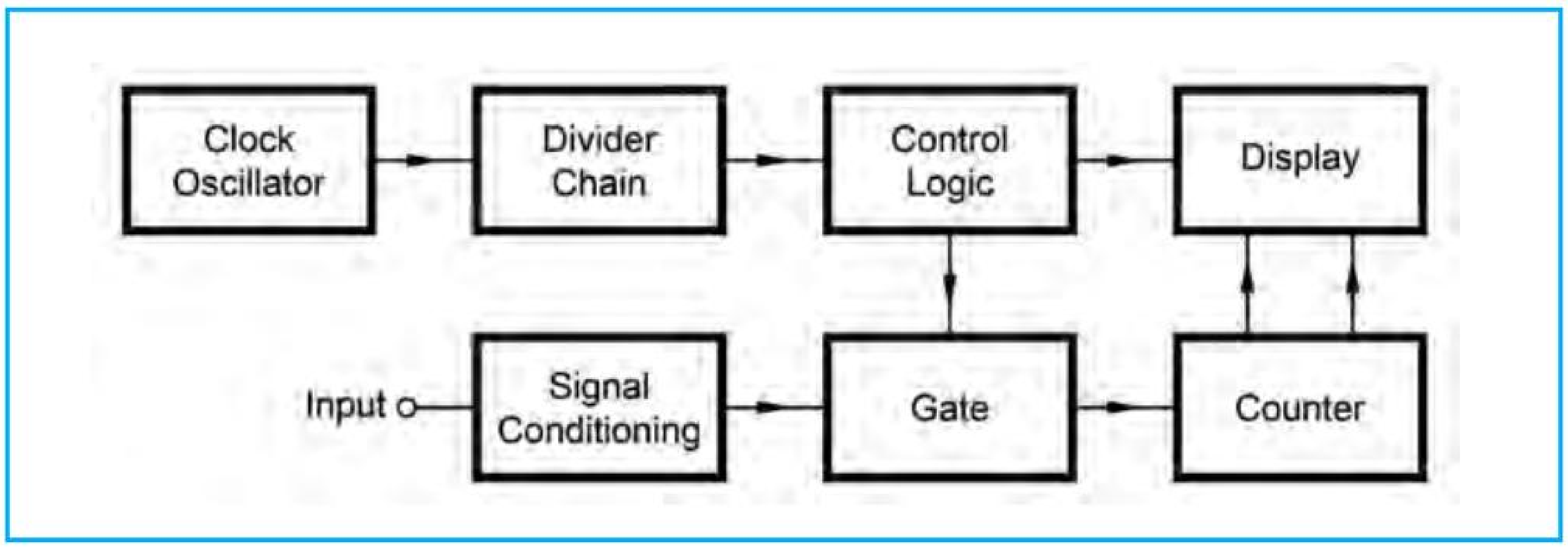

Fig.1. A conventional digital frequency meter uses an arrangement such as this to count the number of input cycles in a given period of time. This method works well when measuring high and very high frequencies, but is impractical at low frequencies

A crystal-controlled clock oscillator and a divider chain are used to generate a gate pulse of suitable duration. This would typically be one second, 100ms, or simlar, so that no mathematics is required in order to convert the number of pulses counted into the corresponding input frequency. It is just a matter of getting the decimal point in the right place. When the gate is open, a counter circuit, which would usually be a series of BCD (binary-coded decimal) counters, registers the number of pulses received during the gate period. This total is fed to a display circuit, which would typically be a latching multi-digit type using seven-segment displays. A control-logic circuit ensures that everything works in the required manner, with the counter being cleared, the gate then being opened, and the final count being latched into the display. Where appropriate, some signal conditioning must be used ahead of the signal gate so that the circuit is supplied with clean pulses at the right logic levels.

Long time, no see

It should be possible to implement a basic pulse-counting frequency meter based on the Raspberry Pi, and this is a subject I will probably return to at a later date. Here, a different approach to frequency measurement will be considered. The pulse counting method is fine when measuring high frequencies. Using a fairly short gate time of (say) 10ms gives quite good accuracy and resolution when the input frequency is tens of MHz or more. On the other hand, it is less satisfactory when measuring low audio and infra-audio frequencies. In fact, the gate time would equate to less than the period of one input cycle! Obviously a longer gate time could be used, but a gate period of many seconds or even minutes would be needed in order to encompass a large enough number of cycles to give good accuracy.

Times up

There is an alternative approach that is more suitable for the measurement of low frequencies, and this is to measure the duration of one cycle. It is necessary to wait for the beginning of a new cycle or half cycle before the measurement can begin, but it still only takes the duration of about 1.5 cycles to make the measurement. This massively reduces the time required to take a reading. For example, with an input frequency of 1Hz it only takes a second or so to make a measurement, whereas it would take several minutes with the pulse counting method.

The timer interface described in the previous *Interface* article lends itself well to the measurement of low and very low frequencies. On the hardware side of things, it basically requires a divide-by-two circuit ahead of the gate input to give a pulse-duration equal to the length of one cycle. A few changes are also required to the software to ensure that no double or partial readings are taken, and to convert the time into its equivalent frequency.

Fig.2 shows the circuit diagram for the clock generator. Like the original circuit, it is based on a 10MHz crystal oscillator, a buffer/amplifier, and a

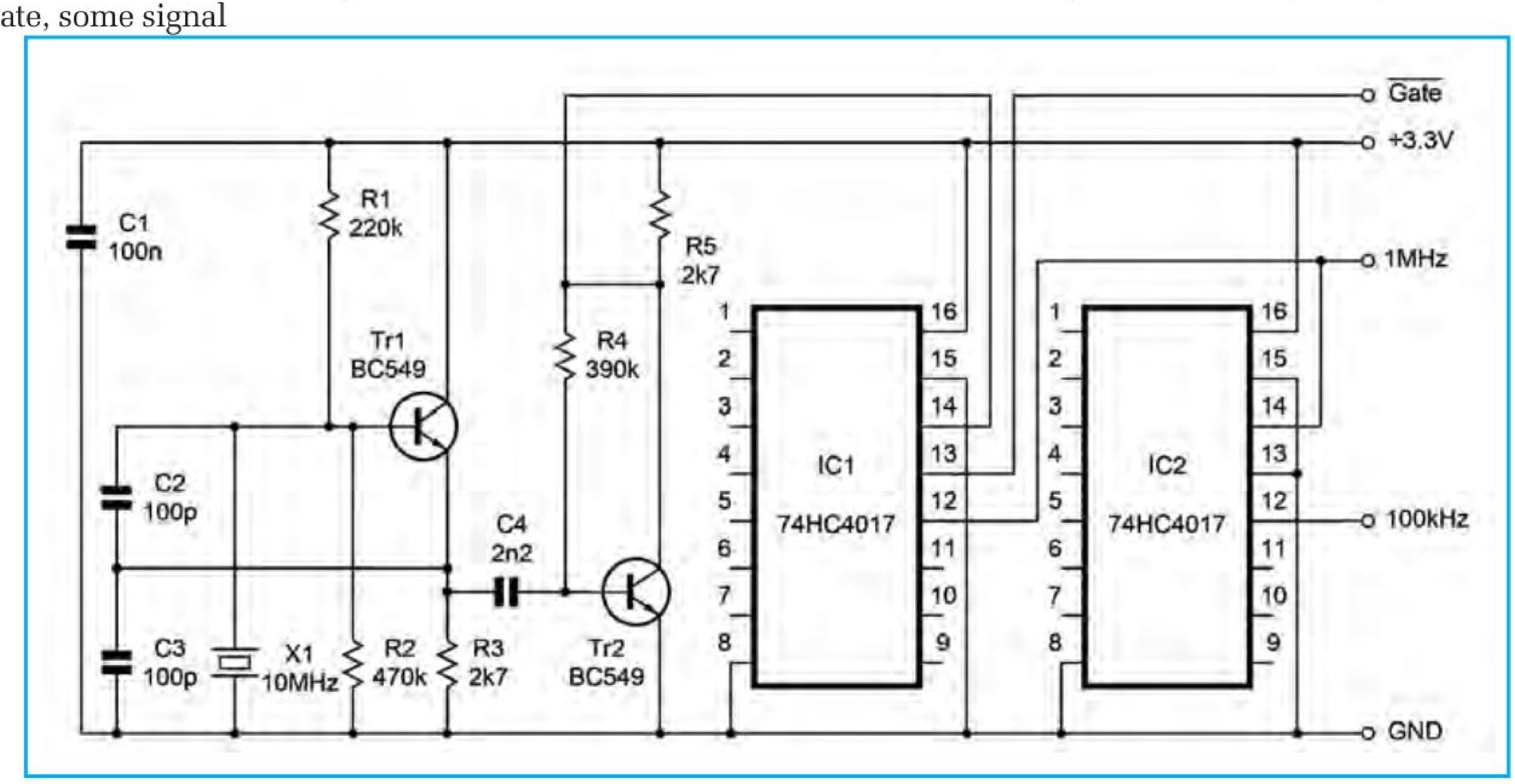

Fig.2. The oscillator and divider stages of the low-frequency meter interface. Two divider stages (IC1 and IC2) are used to derive a 100kHz output signal from the 10MHz clock signal

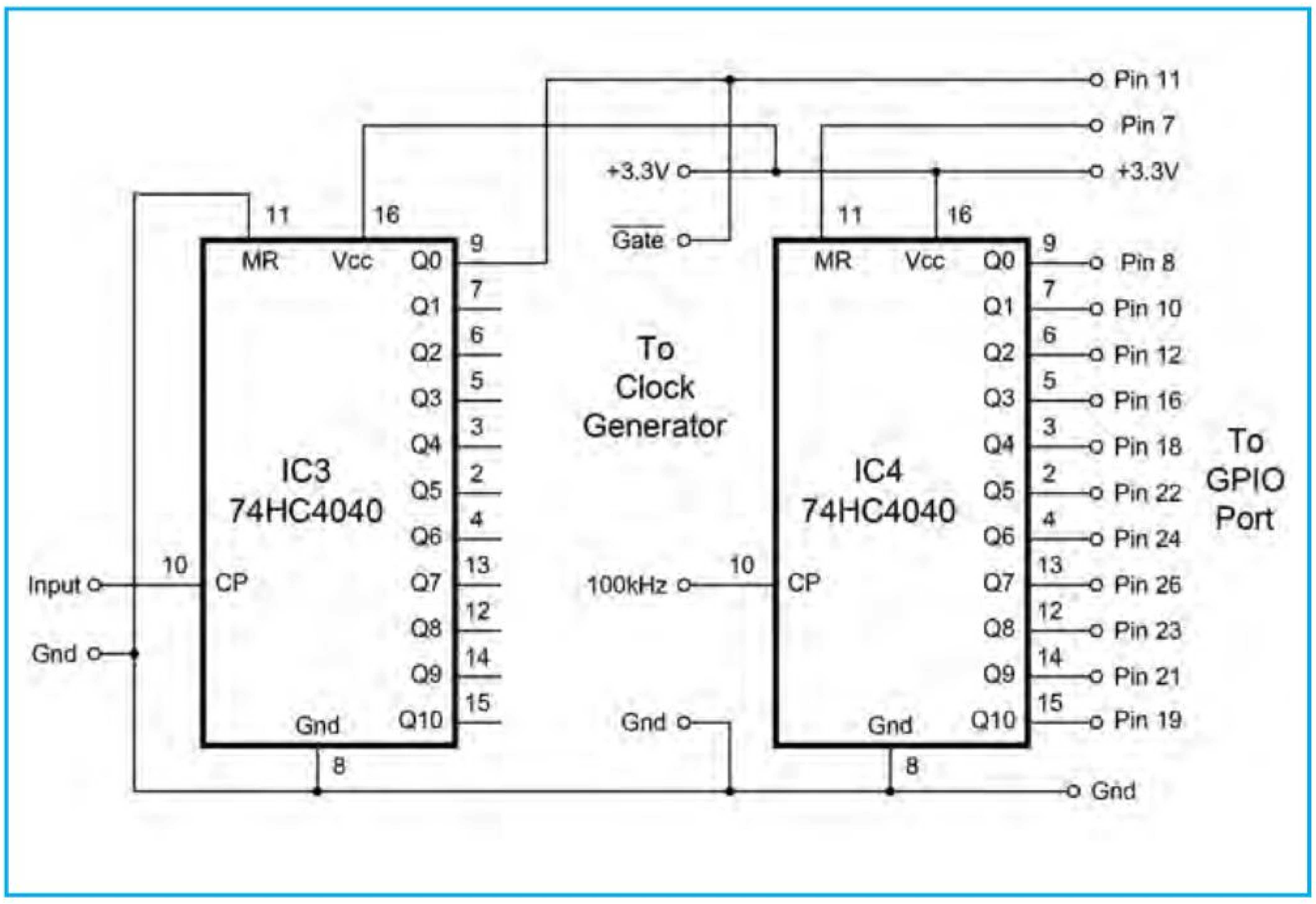

Fig.3. The counter section of the frequency meter. One stage of IC3 is used to divide the input frequency by two, giving output half cycles that have the same duration as one complete input cycle

series of divide-by-ten stages. This is a slightly cut down version of the original circuit, with just two divider stages being included. A high clock frequency is needed for good accuracy, and in this case there are outputs at 1MHz and 100kHz. The latter gives excellent resolution and is the output that I used in the prototype.

The counter circuit appears in Fig.3. This is essentially the same as the equivalent section of the timer circuit, but a 74H4040 (IC3) has been added ahead of the gate input and the main counter chip (IC4). IC3 has the Master Reset input at pin 11 connected to ground so that it runs continuously. The 74HC4040 is a twelve-stage binary counter, but here it is only the Q0 output that is used, giving the required divide-by-two action.

Listing 1 is for a simple Python program that will take a frequency reading. This is essentially the same as the long timer program (Listing 3) in the previous *Interface* article. The timer requires an input signal that is normally high, and it measures the pulse duration when this signal goes low. Provided the input signal is at a fixed frequency, the high and low output times at the Q0 output of IC3 will be the same, and equal to the duration of one input cycle. Consequently, it does not matter whether it is the high or low output time of IC3 that is measured. In this application the output signal from Q0 of IC3 will be at an unknown state when the program is run. An additional `while…loop` is used to provide a hold-off if it is initially in the low state.

The program then operates as before, but measuring the pulse duration in 1/100,000 of a second. In order to convert the final reading from the timer into an equivalent frequency in hertz is just a matter of dividing 100,000 by the reading obtained. This figure followed by 'Hz' is then printed on the screen and the program ends.

New kid on the block

Over the years, the emphasis in the world of computer interfacing has shifted away from PCs towards small computers that are designed to handle this type of thing. The Raspberry Pi has featured in many *Interface* articles, and the other popular choice, the Arduino, has been extensively covered in *EPE* over the last twelve months. There are actually a number of alternatives to these, and using something like 'Raspberry Pi' and 'alternatives' in a search engine will produce details of several popular computer boards. These are no doubt excellent, but being less popular than the market leaders probably means that there is less support for them.

A new computer board was recently introduced, and this is the BBC Micro Bit (Fig.4 and Fig.5). It was originally made available at no charge to schools with year 7 students, but it can now be bought by anyone. It costs £14.95 (about $18) for the basic board, or a few pounds more for a kit that also has a USB lead, battery holder with lead, and two AAA batteries. The ability to operate from a battery supply is obviously a big asset, and it worked well when I tried it with rechargeable Ni-MH batteries, despite their relatively low output voltage. Of course, it can be used in so-called 'tethered mode' in conjunction with a suitable power source.

The processor is a 32-bit ARM Cortex M0. It is a rather different concept to computers such as the Raspberry Pi. It does not connect to a keyboard mouse and monitor and it runs a built-in test

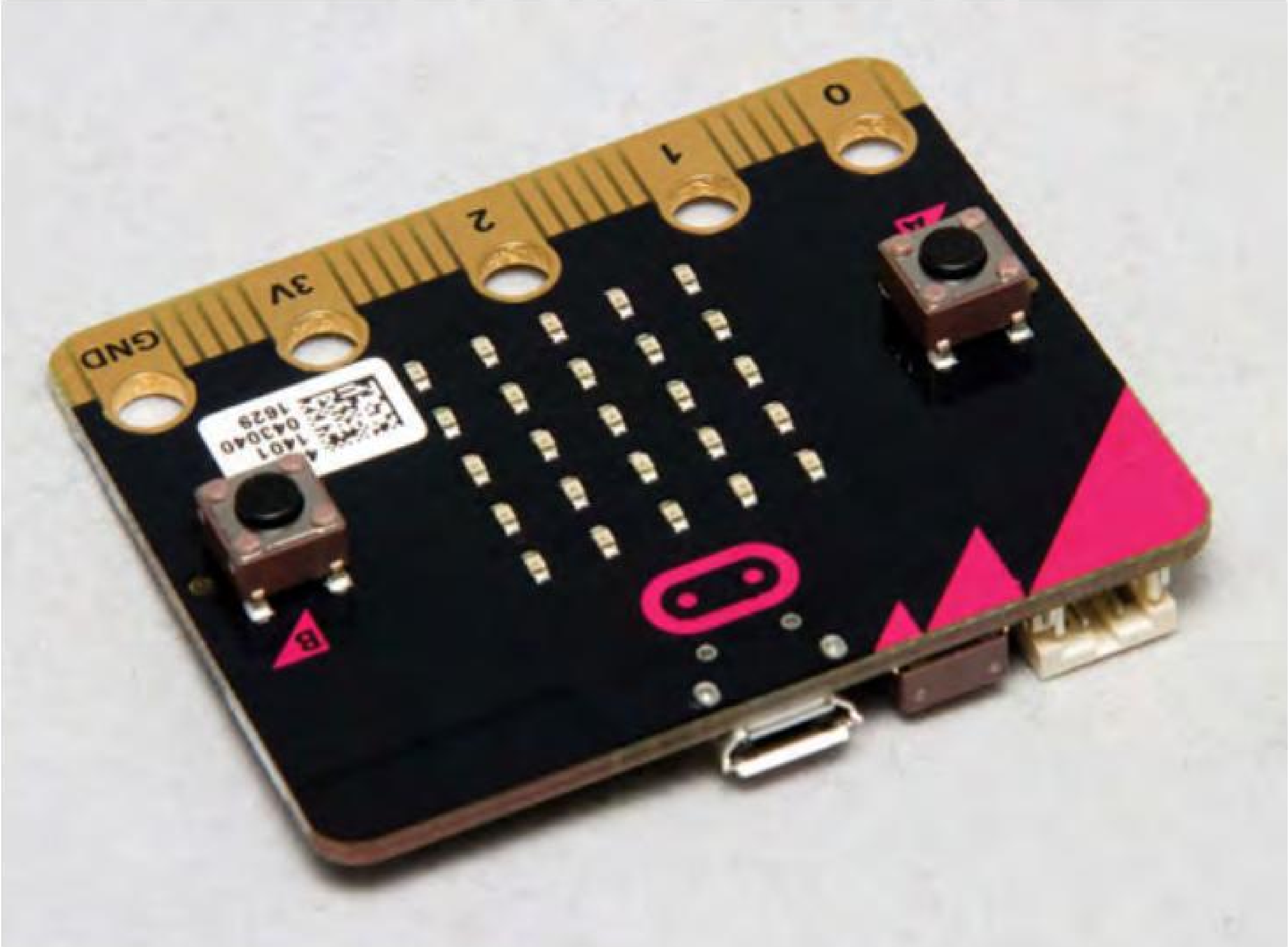

Fig.4. The front side of the BBC Micro Bit board showing the two input buttons and the LED array. It also a built-in accelerometer and a magnetic sensor

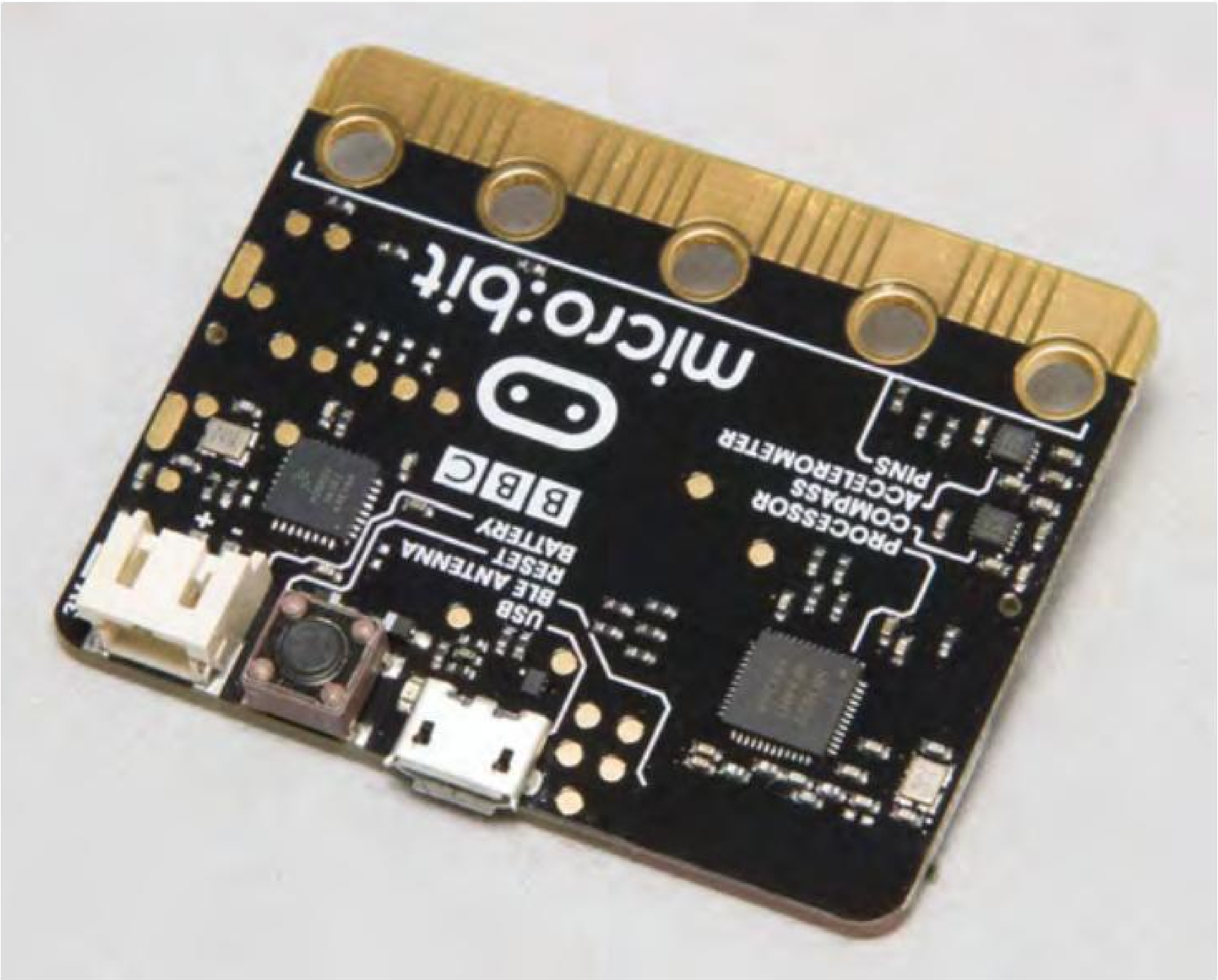

Fig.5. The reverse side of the board, showing the power connector, reset switch and Micro USB port. Opposite these is the edge connector that provides a useful GPIO port – note that some of its input/output lines are shared with hardware on the board.

program when it is connected to a power source. In use, this is replaced with your own programs. These are written on a PC, compiled, and then uploaded to the BBC Micro Bit. In use it is more like a microcontroller-based project than a very basic PC. Various programming languages can be used, including Python, JavaScript and C++.

It has a 5 × 5 matrix of LEDs that can be used to produce scrolling text or simple graphic representations such as arrows and smiley faces. User input is by way of just two pushbutton switches. There are two built-in sensors, which are a three-axis accelerometer and a magnetic sensor. The latter effectively gives it a simple built-in compass. In addition to the Micro USB connector, it can communicate with the outside world via Bluetooth.

GPIO port

You can interface to your own electronic circuits via the edge connector that runs along the bottom of the PCB, and provides a GPIO (general purpose input/output port). There are five large terminals on this connector, and it is not necessary to have a matching female edge connector to use these. Connections to them can be made using small crocodile clips. Ground and a 3.3V supply output are provided, together with three versatile input/output terminals. Each of these can operate as a digital input, a digital output, or an analogue input. No analogue outputs are available, but pulse-width modulation is supported, giving an 'averaged' analogue output capability of sorts.

The good news is that with a suitable connector it is possible to access further input/output lines on the GPIO port. The bad news is that most of these lines are shared with hardware on the board, such as the two switches and the LED display, and they can only be used with the built-in hardware or your own circuits, but not both. While ultimately it is not as potent as a GPIO port such as the one on the Raspberry Pi, it is still extremely useful. The ability to use inputs as analogue types is especially useful, and is actually a feature that the Raspberry Pi lacks. With a resolution of 10-bits, giving returned values in the range 0 – 1023, the analogue inputs are perfectly adequate for many practical applications.

It could probably be used as the basis of real-world applications, but the Micro Bit was designed more as an easy and fun way of learning about programming and interfacing. It works well in this role, and there is already a large amount of support available on the *Internet*. The price is so low that many experienced users will buy it simply for its play value, which it has in abundance.

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Listing 1

```
import RPi.GPIO as GPIO
GPIO.setmode(GPIO.BOARD)
GPIO.setwarnings(False)

GPIO.setup(11, GPIO.IN)
GPIO.setup(8, GPIO.IN)
GPIO.setup(10, GPIO.IN)
GPIO.setup(12, GPIO.IN)
GPIO.setup(16, GPIO.IN)
GPIO.setup(18, GPIO.IN)
GPIO.setup(22, GPIO.IN)
GPIO.setup(24, GPIO.IN)
GPIO.setup(26, GPIO.IN)
GPIO.setup(23, GPIO.IN)
GPIO.setup(21, GPIO.IN)
GPIO.setup(19, GPIO.IN)
GPIO.setup(7, GPIO.OUT)
GPIO.setup(15, GPIO.IN)

GPIO.output(7, False)
GPIO.output(7, True)
GPIO.output(7, False)
byte = 0
overflow = 0
transit = 0

while GPIO.input(11) == GPIO.LOW:
   pass
while GPIO.input(11) == GPIO.HIGH:
   pass
while GPIO.input(11) == GPIO.LOW:
   cntin = GPIO.input(19)
   if GPIO.input(19) == GPIO.HIGH and transit == 0:
      overflow = overflow + 1
      transit = 1
   if GPIO.input(19) == GPIO.LOW and transit == 1:
      transit = 2
   if GPIO.input(19) == GPIO.HIGH and transit == 2:
      transit = 0

if GPIO.input(8):
   byte = byte + 1
if GPIO.input(10):
   byte = byte + 2
if GPIO.input(12):
   byte = byte + 4
if GPIO.input(16):
   byte = byte + 8
if GPIO.input(18):
   byte = byte + 16
if GPIO.input(22):
   byte = byte + 32
if GPIO.input(24):
   byte = byte + 64
if GPIO.input(26):
   byte = byte + 128
if GPIO.input(23):
   byte = byte + 256
if GPIO.input(21):
   byte = byte + 512

overflow = overflow * 2048
byte = byte + overflow
byte = 100000/byte
print (byte, "Hz")

GPIO.cleanup()
print ("Finished")
```

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AUDIO OUT

By Jake Rothman

Totally derailed: powering amplifiers – Part 2

Welcome back to this short series on getting the most from power amplifiers by correctly providing the 'right' kind of power. This month, we will deal with speaker return currents, power rails and decoupling – but, before that, last month I didn't quite have space to include a note on implementing a PCB design for the basic dual-rail design of Fig.2. I often use what I call the 'diamond' layout, which is basically just a double version of single-supply noding. This is shown in Fig.13.

Speaker return current

The speaker return current can be a source of instability if it causes a potential difference resulting in positive feedback. The rule is to node the speaker ground terminal on to the smoothing capacitors' ground. In dual-rail systems use the stub from the rectifier ground. For single-rail supplies, it can either be connected to the main smoothing capacitor's ground or to the output stage ground pin. Often, it is noded to the lower output transistor shown in Fig.14. This keeps the negative half-wave current pulses circulating locally, rather than back to the smoothing capacitor, which may reduce radiated interference and help with high frequency stability. Fig.15 shows a nasty distorted half-wave earth current, which may impose itself on the signal if a speaker earth return is connected to the lower transistor earth pin. Similarly, if the amplifier's power rail decoupling capacitor is large (> few hundred µF) then sufficiently large ripple current pulses will pass through the ground connection from the speaker for these to be audible. Therefore, it is usually best to connect the speaker to the main smoothing capacitor node.

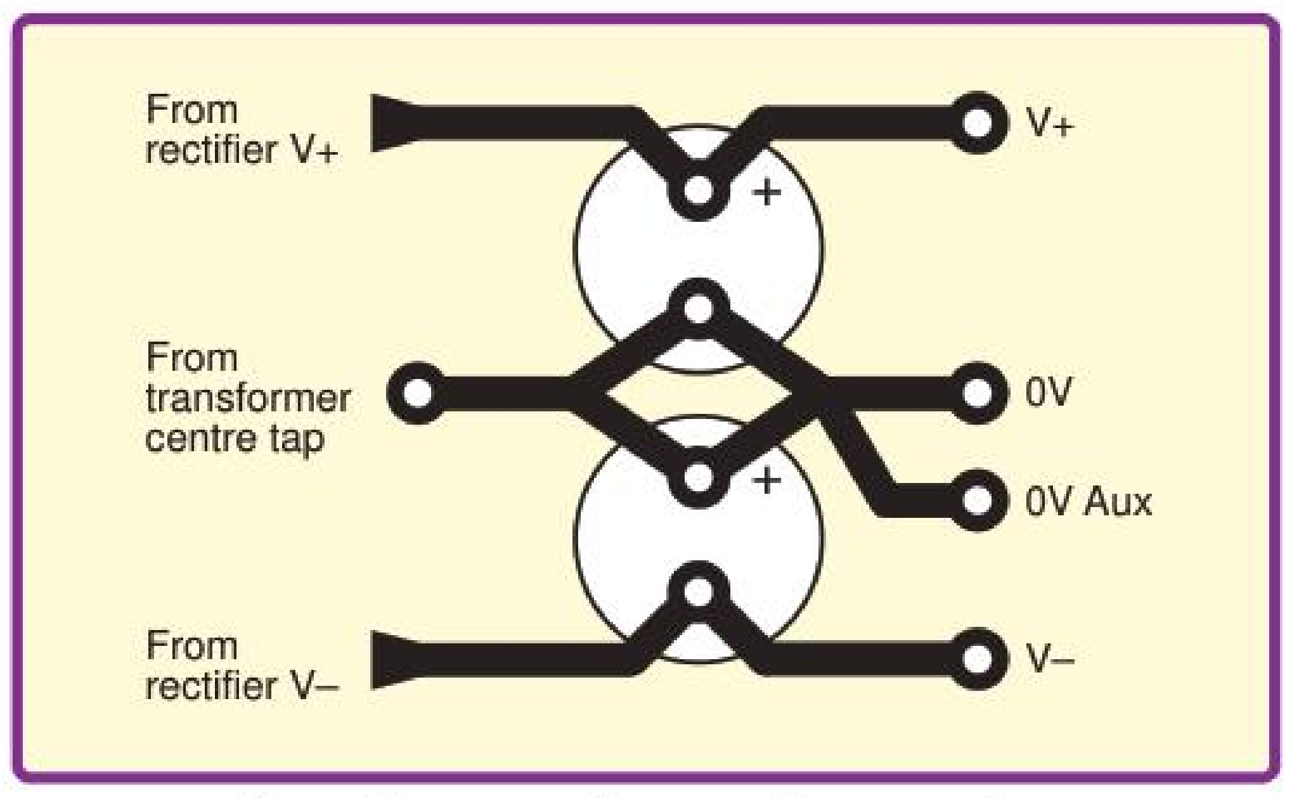
From rectifier V+
V+
+
From transformer centre tap
0V
+
0V Aux
From rectifier V–
V–

Fig.13. The 'diamond' PCB layout for dual-rail power supplies – see Fig.2.

Power corrupts

Power-rail-induced distortion is a major problem in class AB power amps. It has to be remembered that the output transistors switch on and off alternately. This means that there is a half-wave rectified version of the audio feeding the plus and minus rails, as shown in Fig.16. This sounds like the worst fuzz box in the world playing in the background and it can easily contaminate the audio through inductive and capacitive coupling. This can happen if one power rail runs near a sensitive track. If the two power rail cables are twisted together, the radiated two halves of the waveform are combined back together and cause no trouble. This technique was first described by Doug Self (*Wireless World*, Feb 1994) and further developed by Leo Simpson. On a double-sided PCB the same effect can be achieved by running the power tracks on top of each other. This was done on the PCB for the *Ultra-LD 200W Power Amplifier* (*EPE*, Aug 2010). It is worth studying the layout in this board since it is one of the best, embodying all the techniques described here. Solid ground plane techniques although excellent for RF, low power and digital circuits, do not work very well for high-current audio applications. This is because it is difficult to predict where the currents will flow unless it is very carefully partitioned. This is often a trial and error approach dealt with by cutting grooves. The same problem occurred with valve amplifier chassis, where multiple earth points used tag strip screw mounting points. Modern valve amplifiers usually use an earth bus of thick tinned copper wire. The single star earth point preached by some Hi-Fi 'gurus' doesn't seem to work very well either, the web of long wires inviting instability. Generally, good amplifier grounding involves several ground nodes.

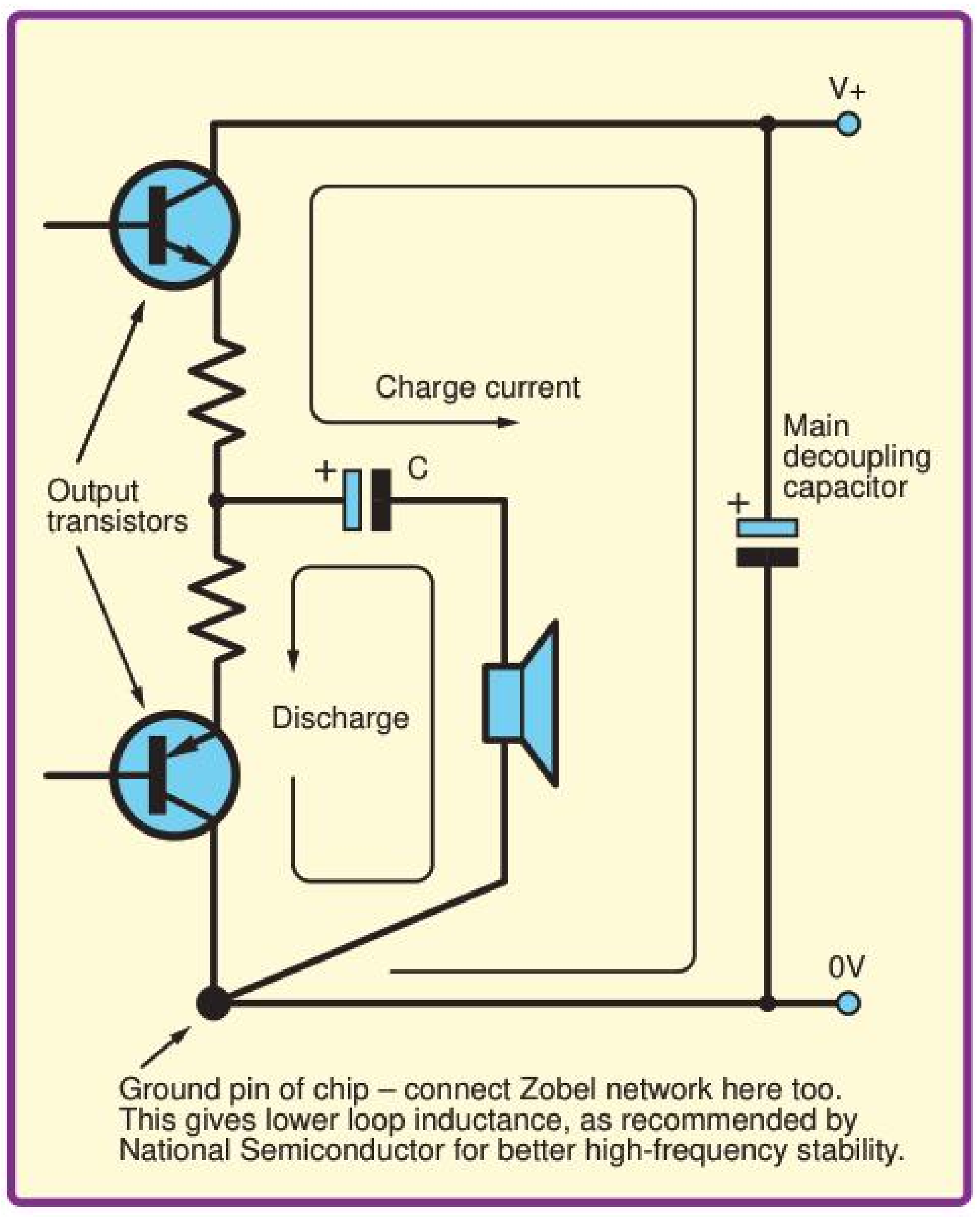
V+
Charge current
Output transistors
+
C
Main decoupling capacitor
+
Discharge
0V
Ground pin of chip – connect Zobel network here too. This gives lower loop inductance, as recommended by National Semiconductor for better high-frequency stability.

Fig.14. Speaker current return path.

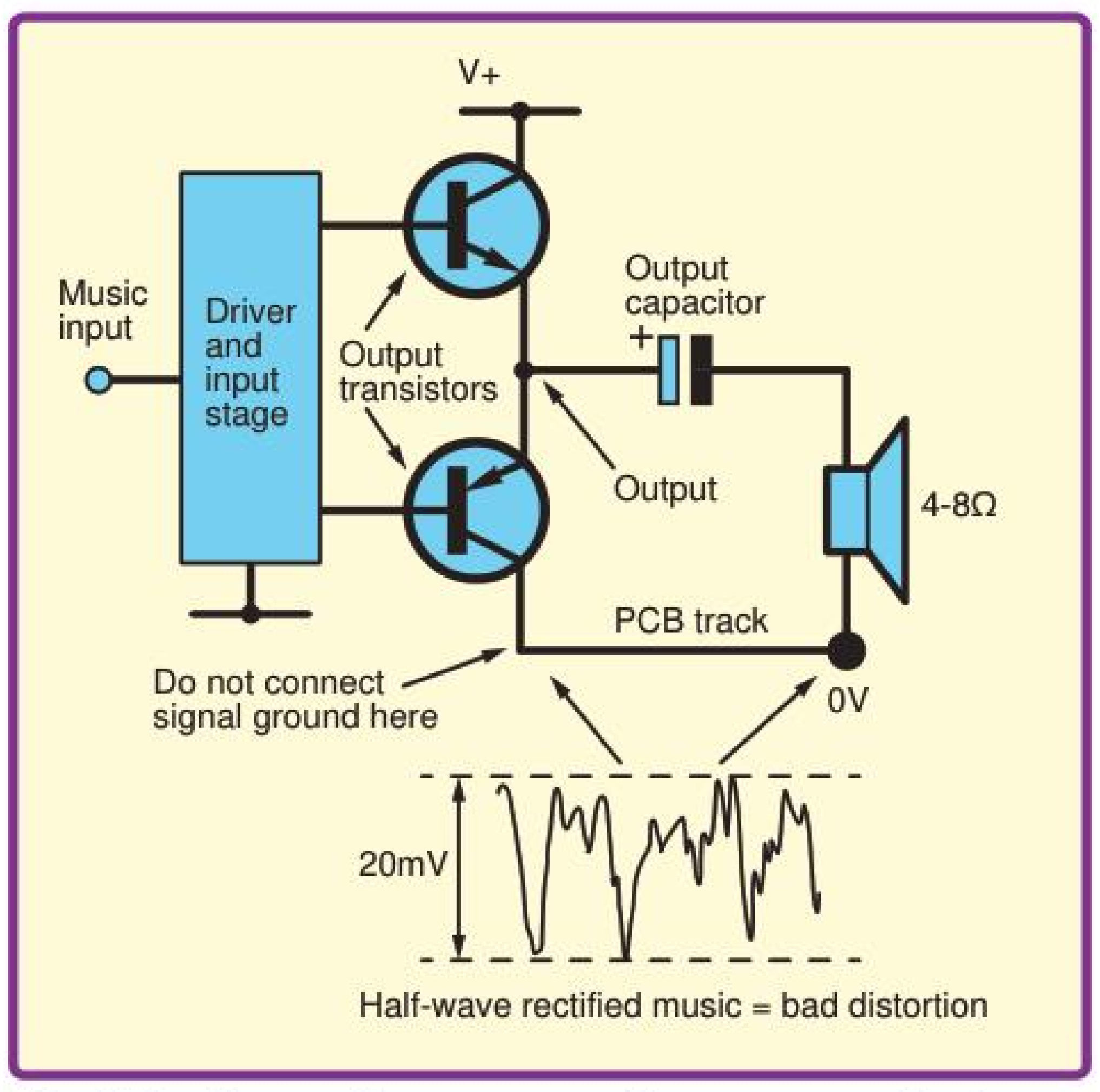
V+
Music input
Driver and input stage
Output transistors
Output capacitor
+
Output
4-8Ω
PCB track
Do not connect signal ground here
0V
20mV
Half-wave rectified music = bad distortion

Fig.15. Sometimes speaker current is returned to the lower output transistor. This keeps the circulating current more local, but decoupling capacitors can put hum current down the earth rail.

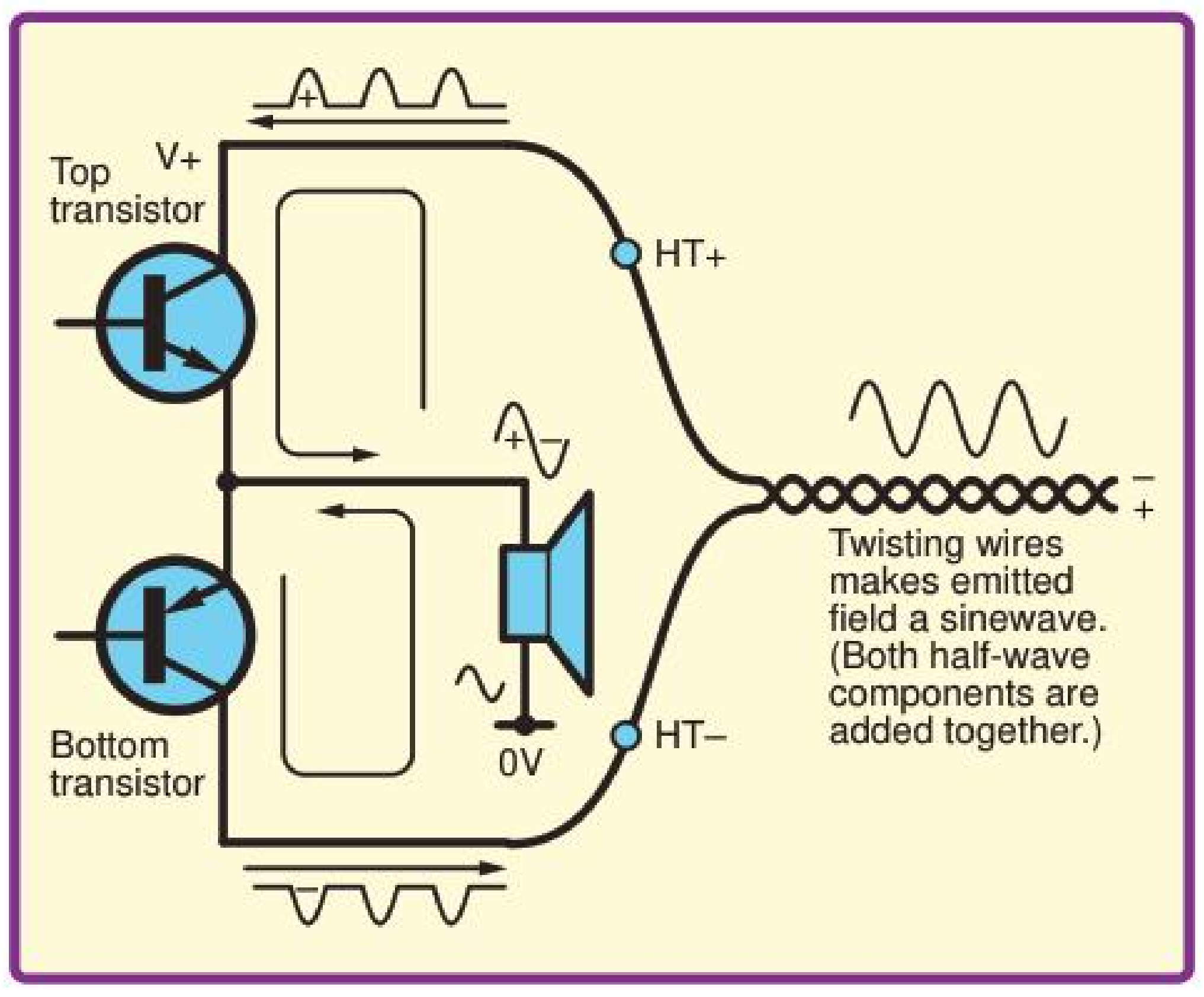
+
Top transistor
V+
HT+
+
–
+
Twisting wires makes emitted field a sinewave. (Both half-wave components are added together.)
Bottom transistor
0V
HT–
–

Fig.16. Radiation of positive and negative halves of audio can be kept summed together by twisting cables or using parallel tracks.

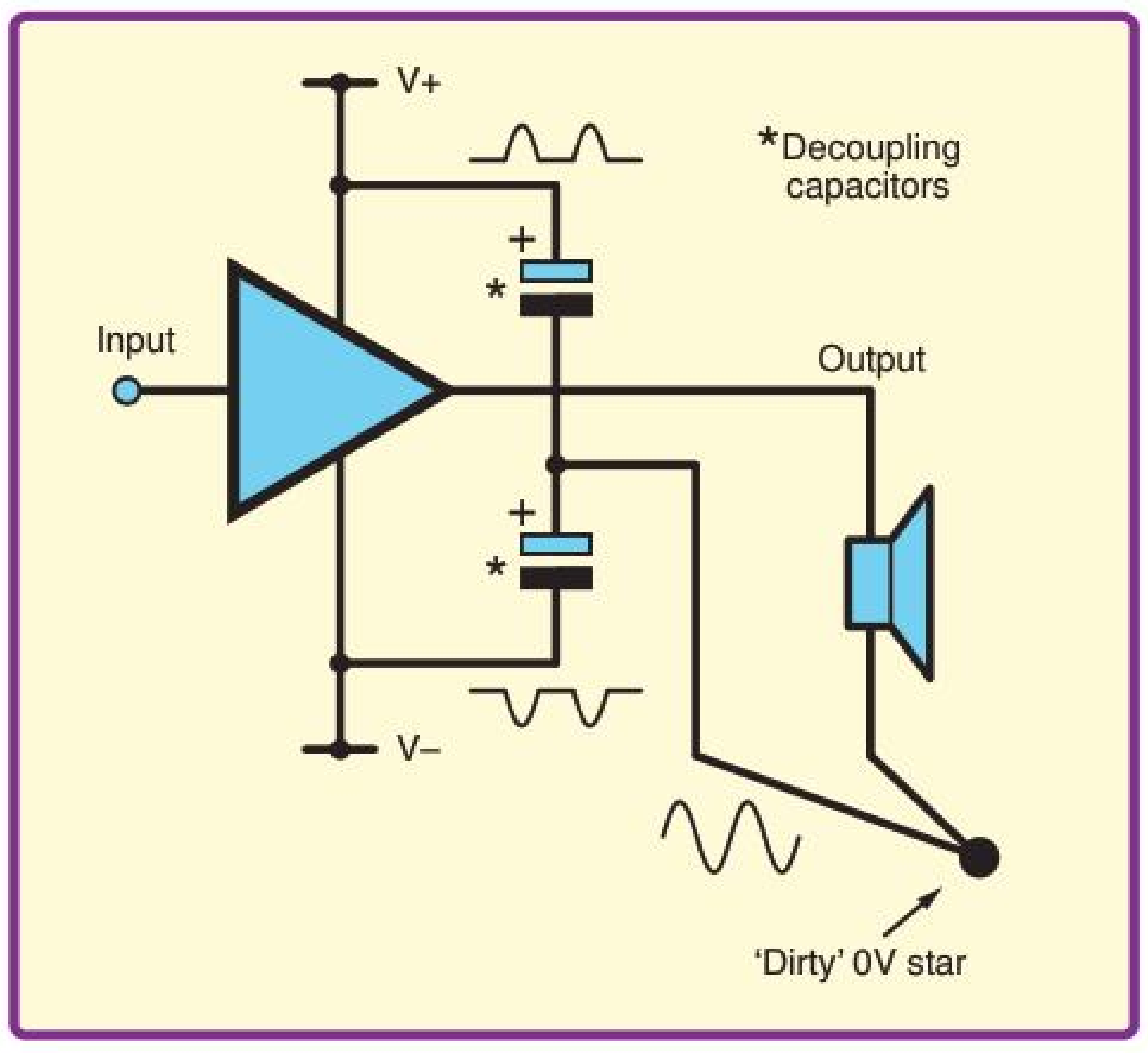
V+
*Decoupling capacitors
Input
Output
V–
'Dirty' 0V star

Fig.17. The earth currents of decoupling capacitors should also be summed together.

Decoupling

Constructors also have to be careful with decoupling capacitors in dual-rail designs, ensuring that the two half-wave audio component currents sum together at one point, as illustrated in Fig.17. Often, a single decoupling capacitor from the positive to the negative rail can be used, avoiding this problem. This technique works well with 5532 op amps and LM3886 power amplifiers. It was the approach used by Manfred Mornhinweg on his active speaker PCB, see **http://ludens.cl**. Note that where the driver and output stage power rail wires are separated, high frequency instability can occur. This can be eliminated by joining the two points on the PCB with small ceramic capacitors, shown dotted on the diagram (Fig.19). If decoupling capacitors are large enough, say greater than 100µF, they should be connected to the 'dirty' ground, since the ripple current passing through may increase hum if it is connected to the signal ground. Local regulation or capacitance multipliers avoid this problem because they don't put large ripple currents to ground.

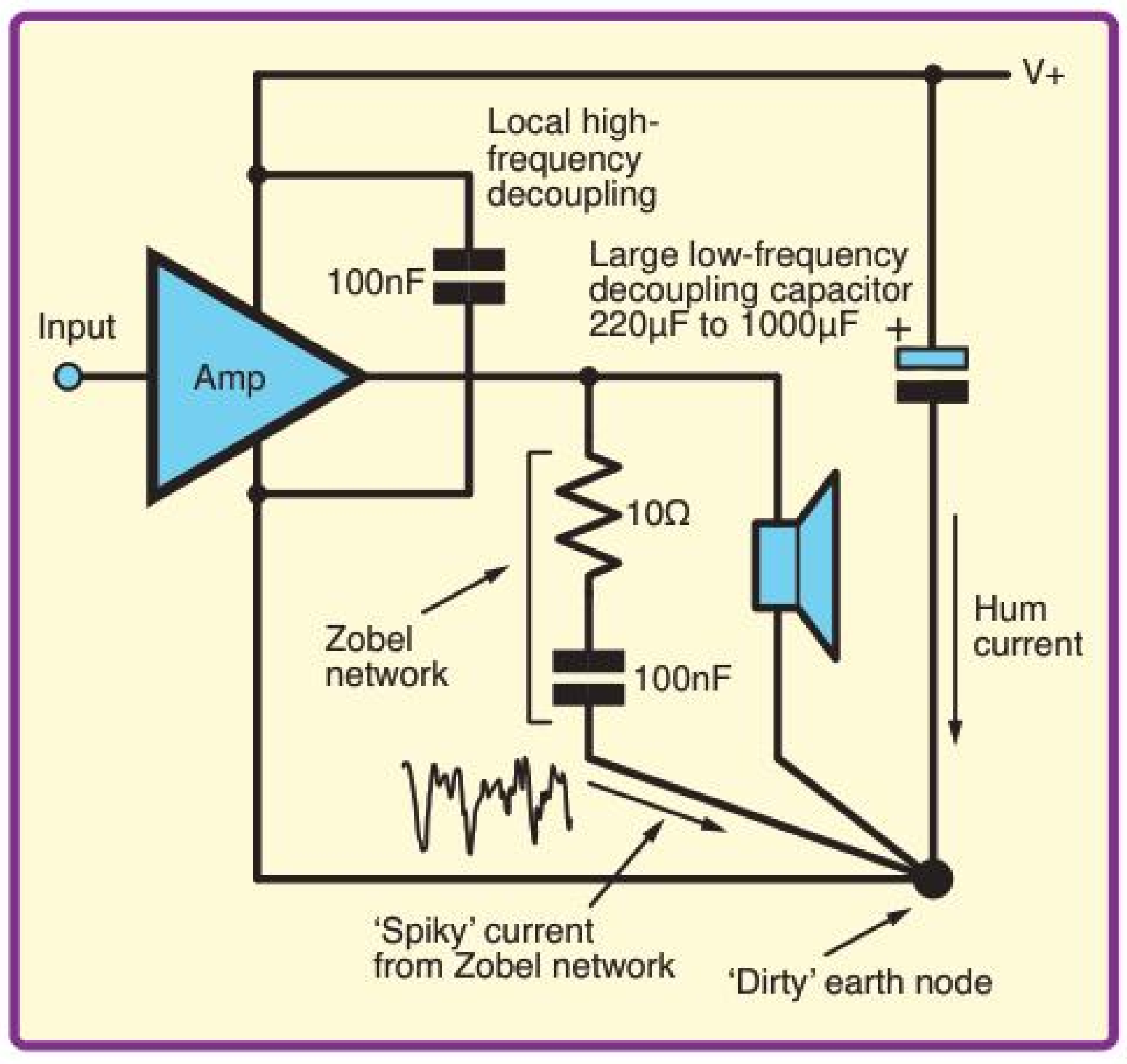
V+
Local high-frequency decoupling
100nF
Large low-frequency decoupling capacitor 220µF to 1000µF
Input
Amp
10Ω
Zobel network
100nF
Hum current
'Spiky' current from Zobel network
'Dirty' earth node

Fig.18. The Zobel network current is spiky and should be routed so it does not contaminate the signal ground.

Zobel network

In a Zobel network, a high-pass filtered version of the output signal flows. This spiky current can cause problems and should go to a 'dirty ground', such as the decoupling or smoothing capacitor shown in Fig.18. On some chips, long leads from the Zobel may cause HF instability on the negative cycle.

Mono amplifier wiring layout

There are usually three star earth points in single-rail amplifiers: signal ground, dirty power supply ground and the power supply rectifier star point. These are shown in Fig.19, which represents the amplifier as a power op amp. It could be one of the single chip-based Gainclone amplifiers (A generic internet term for a minimalist power amplifier based on chips, such as the LM3886) or a power amplifier module. I've developed this scheme installing many modules by Bi-Pak, ILP, Crimson Elektrik, Maplin and Hypex. There are occasionally power connections and grounds for voltage references, bias decoupling capacitors and driver stages. These normally go to the signal ground since the currents are low. These connections can be done on the board so long as there is a decoupling capacitor to star to. If the amplifier only has one earth pin, such as the LM386, take care to join the signal earth and dirty earth at the pin, as shown in Fig.20.

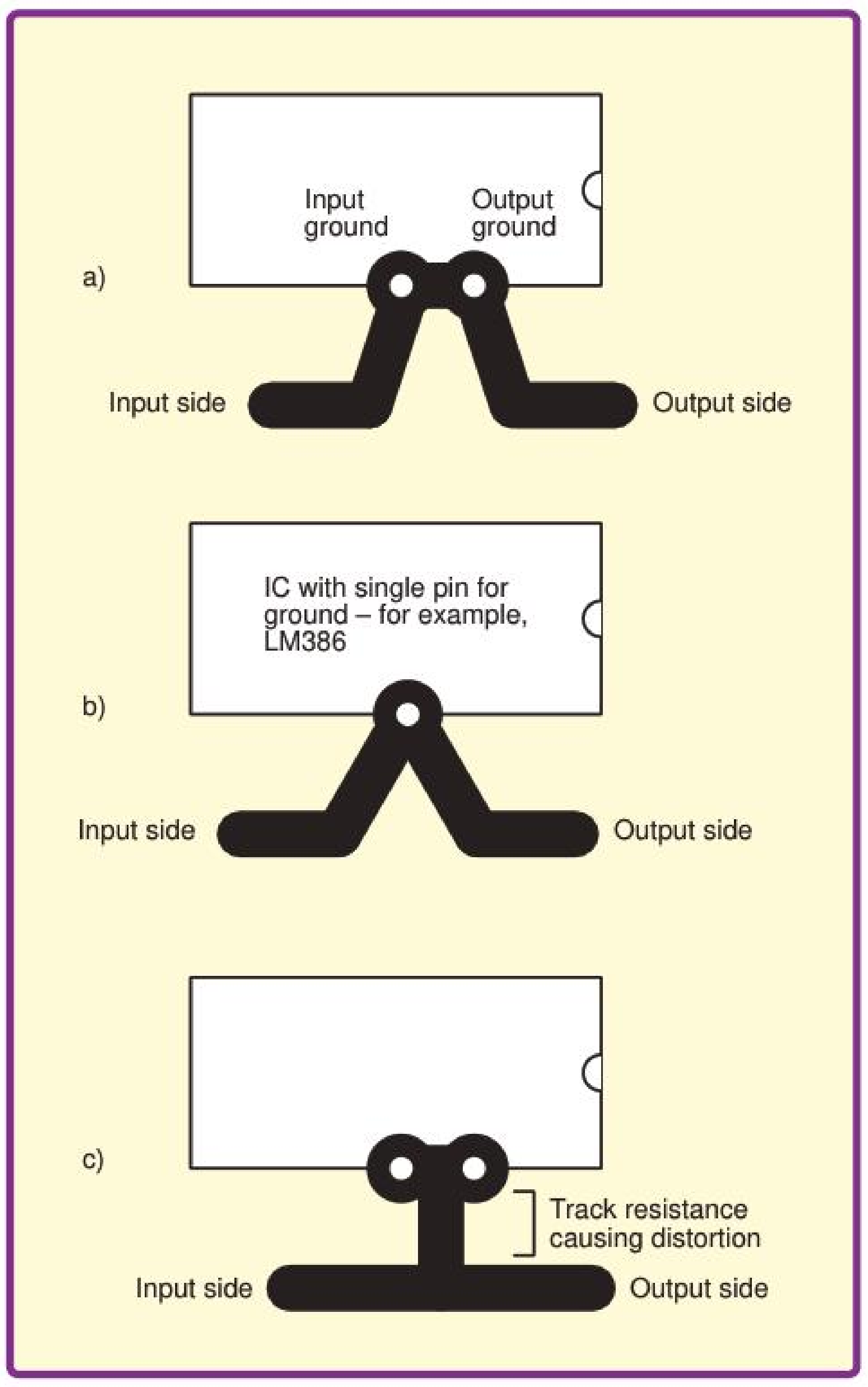
a)
Input ground
Output ground
Input side
Output side
b)
IC with single pin for ground – for example, LM386
Input side
Output side
c)
Track resistance causing distortion
Input side
Output side

Fig.20. If an amplifier IC has only one earth pin, ensure the signal and power earths are starred at the pin: a) and b) – good practice; c) bad practice.

Next month

In *Part 3*, next month I will conclude this short series with a look at mains ground and stereo hum.

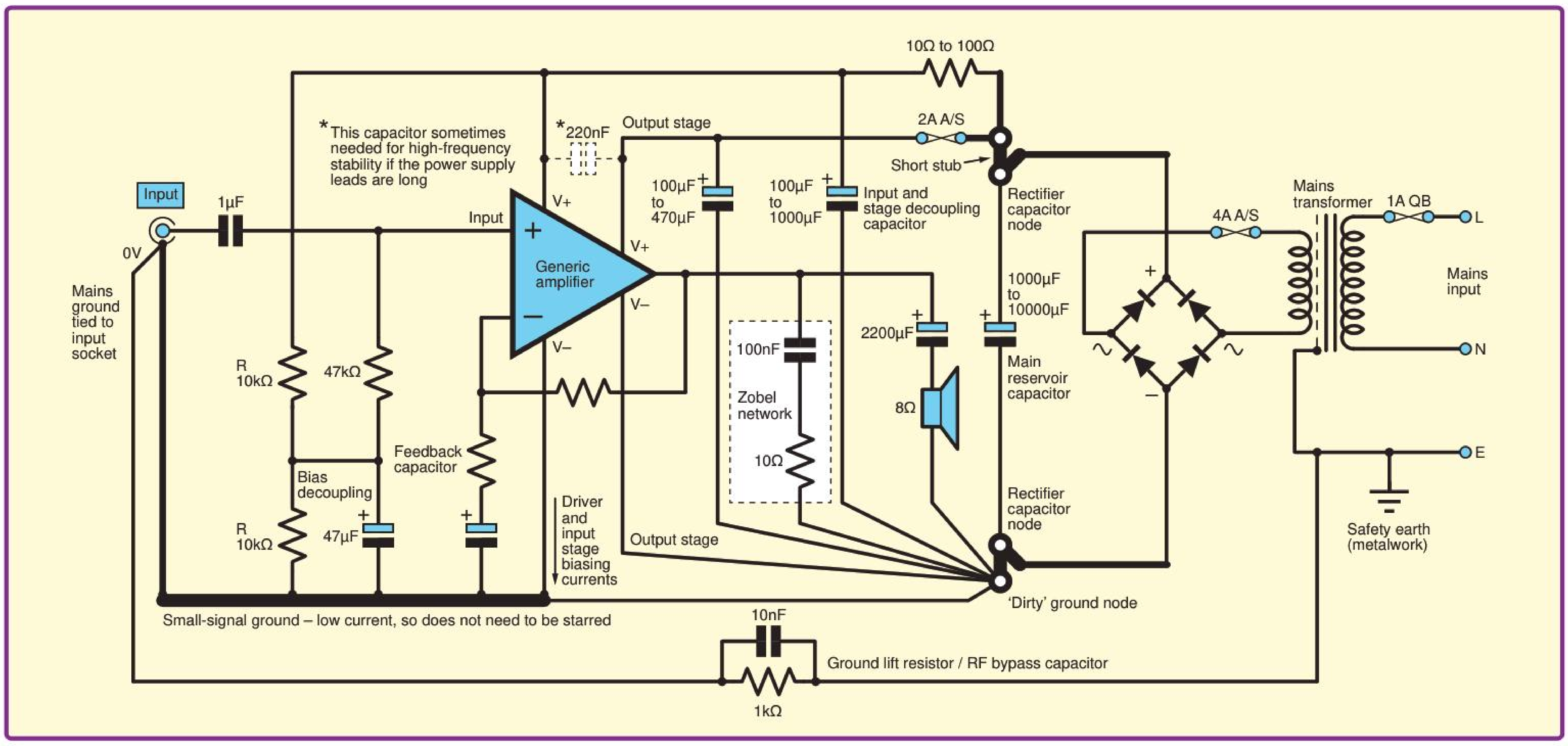
10Ω to 100Ω
*This capacitor sometimes needed for high-frequency stability if the power supply leads are long
*220nF
Output stage
2A A/S
Short stub
Input
1µF
0V
Mains ground tied to input socket
100µF to 470µF
100µF to 1000µF
Input and stage decoupling capacitor
Rectifier capacitor node
Mains transformer
1A QB
4A A/S
L
Mains input
N
E
V+
Input
Generic amplifier
V–
1000µF to 10000µF
2200µF
Main reservoir capacitor
100nF
Zobel network
10Ω
8Ω
R 10kΩ
47kΩ
Feedback capacitor
Bias decoupling
R 10kΩ
47µF
Driver and input stage biasing currents
Output stage
Rectifier capacitor node
'Dirty' ground node
Safety earth (metalwork)
Small-signal ground – low current, so does not need to be starred
10nF
Ground lift resistor / RF bypass capacitor
1kΩ

Fig.19. Generic single-rail amplifier power supply and wiring scheme. Single-star earthing advocated by 'Hi-Fi gurus' is not optimal. At least three nodes are normally required. This can be extended to dual-rail designs, which will be described in a later article.

HP 34401A Digital Multimeter 6 ½ Digit

HP 54600B Oscilloscope Analogue/Digital Dual Trace 100MHZ

MARCONI 2955B Radio Communications Test Set

FLUKE/PHILIPS PM3092 Oscilloscope 2+2 Channel 200MHZ Delay TB, Autoset etc

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IFR 2025	Signal Generator 9kHz - 2.51GHZ Opt 04/11	£900
Marconi 2955B	Radio Communications Test Set	£800
R&S APN62	Syn Function Generator 1HZ-260KHZ	£195
Fluke/Philips PM3092	Oscilloscope 2+2 Channel 200MHZ Delay etc	£250
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HP6624A	PSU 4 Outputs	£350
HP6632B	PSU 0-20V 0-5A	£195
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Marconi 2030	Synthesised Signal Generator 10KHZ-1.35GHZ	£750
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Marconi 2440	Counter 20GHZ	£295
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Marconi 6200B	Microwave Test Set	£2,300
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Black Star Orion	Colour Bar Generator RGB & Video	£30
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Fluke 99B	Scopemeter 2 Channel 100MHZ 5GS/S	£125
Gigatronics 7100	Synthesised Signal Generator 10MHZ-20GHZ	£1,950
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Seaward Nova	PAT Tester	£95
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Solartron 7150 Plus	as 7150 plus Temp Measurement	£75
Solatron 7075	DMM 7 1/2 Digit	£60
Solatron 1253	Gain Phase Analyser 1mHZ-20KHZ	£600
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Max's Hot Beans

By Max The Magnificent

Fill yer stockings!

Good grief. I cannot believe that the Crimble Holidays are almost upon us (I'm still winding down from the Y2K festivities). Have you got all your Christmas shopping done? If not, may I offer a few stocking filler suggestions for you to buy for a loved one (or for you to drop a hint to your loved one…)

Music

Everyone has their own musical favorites, plus there are a variety of streaming services, like Spotify (**http://spoti.fi/Jyh4sn**), so it would be pointless for me to suggest most artists or albums here. Having said this, if you haven't already got them, I would heartily recommend the Animusic #1 and #2 DVDs (**http://bit.ly/2fbhCIJ**). These contain a wide variety of spectacular animation-music pieces, such as the Cathedral Pictures track that you can see on YouTube (**http://bit.ly/2fbhUiU**), and they are well-worth the ~$30 for the 2-DVD combo. (Note that I will be giving US prices / URLs, because that's where I live these days.)

Gadgets and gizmos

One of the things I have sitting on the desk in my office is a challenging 3D labyrinth contained within a sphere called the Perplexus Epic (**http://amzn.to/2edYpBR**), which provides hours of fun for only ~$20. In addition to keeping me busy, anyone visiting my office invariably picks this little scamp up and has a play with it.

Slightly more expensive at ~$70 is the Mindflex Game (**http://amzn.to/2e2lOen**). The idea here is to use sensors in a lightweight headset to measure your brainwaves and guide a small foam ball through a customisable obstacle course. Once again, this has provided me with hours of amusement (one day, I hope to complete the course!).

As you may recall from my recent columns, I've purchased an Oculus Rift virtual reality headset along with a computer powerful enough to drive it. Of course, this high-end system isn't cheap, but virtual reality is a lot of fun, so I really recommend that you at least dip your toes in the water. In reality, you can pick up a variety of pretty decent virtual reality headsets like the VR Box (**http://amzn.to/2fvCWKw**) for around $20. The main advantages of these little scamps are that they are cheap and that they work with just about any smartphone on the planet. The main disadvantage is the mostly low-end quality of the currently available content.

Fig.1. Amazing CGI cathedral artwork from Animusic

Moving up the food chain a little, we have the Gear VR from Samsung for ~$60 (**http://amzn.to/2bWdeJ6**). The advantage here is a better user interface and higher-quality curated content; the disadvantage is that it only works with Samsung's smartphones. I'm also hearing good reports regarding Google's recently launched ~$80 Daydream View headset (**http://bit.ly/2eUUttL**), which works with Google's new Pixel smartphones.

If you have the money, however, I think you should take a look at the ~$399 PlayStation VR headset (**http://amzn.to/2e1WC47**). In addition to being a great ergonomic design, this little beauty is backed by a wealth of triple-A virtual reality games and other content. Of course, it's important to note that you will also require a ~$299 PlayStation 4 system (**http://bit.ly/1tQifFi**) to drive it, or – preferably – a ~$399 PlayStation 4 Pro (**http://bit.ly/2cr0n3r**).

Books

Since we were just talking about virtual reality, we have to lead off our book suggestions with *Ready Player One* by Ernest Cline (**http://amzn.to/2ee26Y9**). This is set in the year 2044 when reality is rather gruesome, so folks spend a lot of time jacked into a virtual reality utopia known as OASIS. Just before the guy who created OASIS dies, he announces a puzzle competition, the winner of which will inherit his vast fortune. When our hero, young Wade Watts, cracks the first clue, he quickly finds that other players are prepared to kill in order to win the ultimate prize. All I can say is that this is a masterpiece of a first-time book, and that it had me sitting on the edge of my seat.

At the other end of the spectrum we have two books about living at the bottom rung of society in Victorian Britain. I personally think that we (the folks living in places like America and Western Europe) are currently living in the Golden Age; also, that most of us don't realise how lucky we are. When I last visited my dear old mum in England, I saw a program on TV called *The Victorian Slum* (**http://bbc.in/2dDzQ61**), which really gave a feel for how hard life used to be. For those who want to know more about that time, two books I'd recommend are *London Labour and the London Poor* by Henry Mayhew (**http://amzn.to/2fEMvpK**) and *Angel Meadow* by Dean Kirby (**http://amzn.to/2eebJWF**).

Last, but not least, on the science and technology side of things, three books that I recently read and that I heartily endorse are T*he Innovators* by Walter Isaacson (**http://amzn.to/2eVcoQO**), *Algorithms to Live By* from Brian Christian and Tom Griffiths (**http://amzn.to/2fibJGe**), and *Genome* by Matt Ridley (**http://amzn.to/2feIPZh**). Happy Christmas to all!

Any comments or questions? – please feel free to send me an email at: **max@CliveMaxfield.com**

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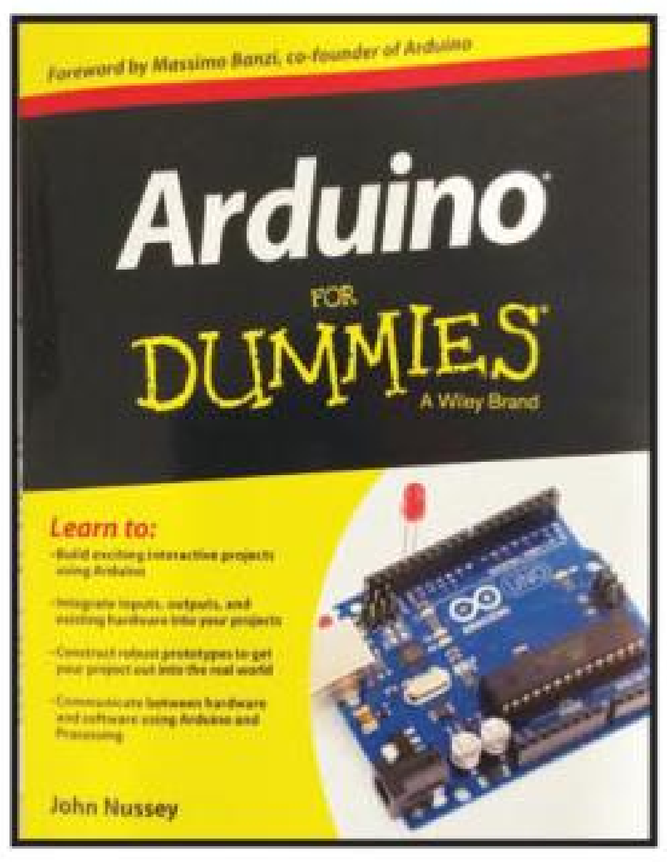

ARDUINO FOR DUMMIES
John Nussey

Arduino is no ordinary circuit board. Whether you're an artist, a designer, a programmer, or a hobbyist, Arduino lets you learn about and play with electronics. You'll discover how to build a variety of circuits that can sense or control real-world objects, prototype your own product, and even create interactive artwork. This handy guide is exactly what you need to build your own Arduino project – what you make is up to you!

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- Solder on! – don't know a soldering iron from a curling iron? No problem! You'll learn the basics and be prototyping in no time.
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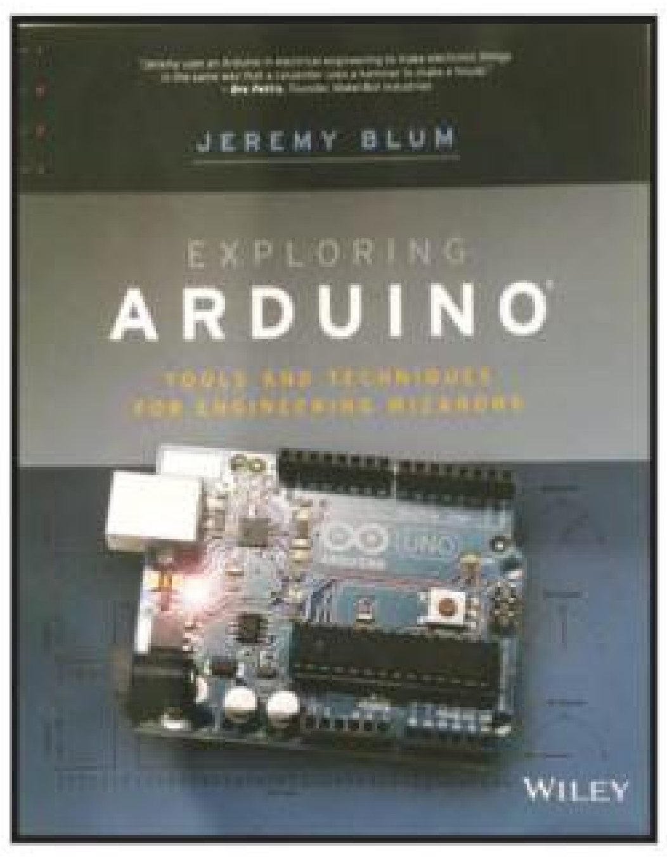

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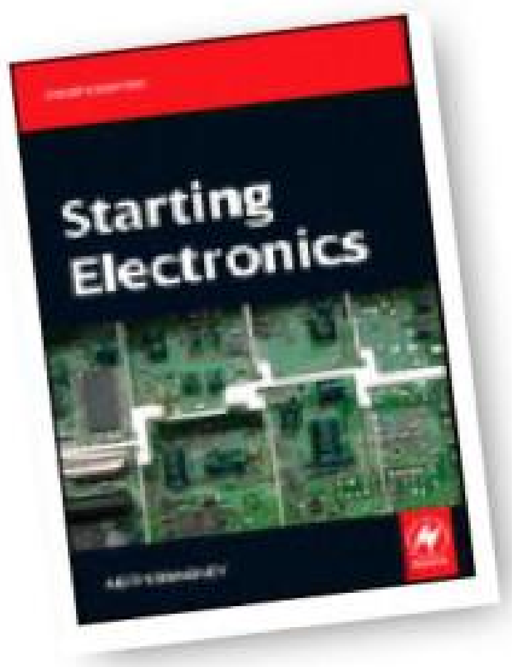

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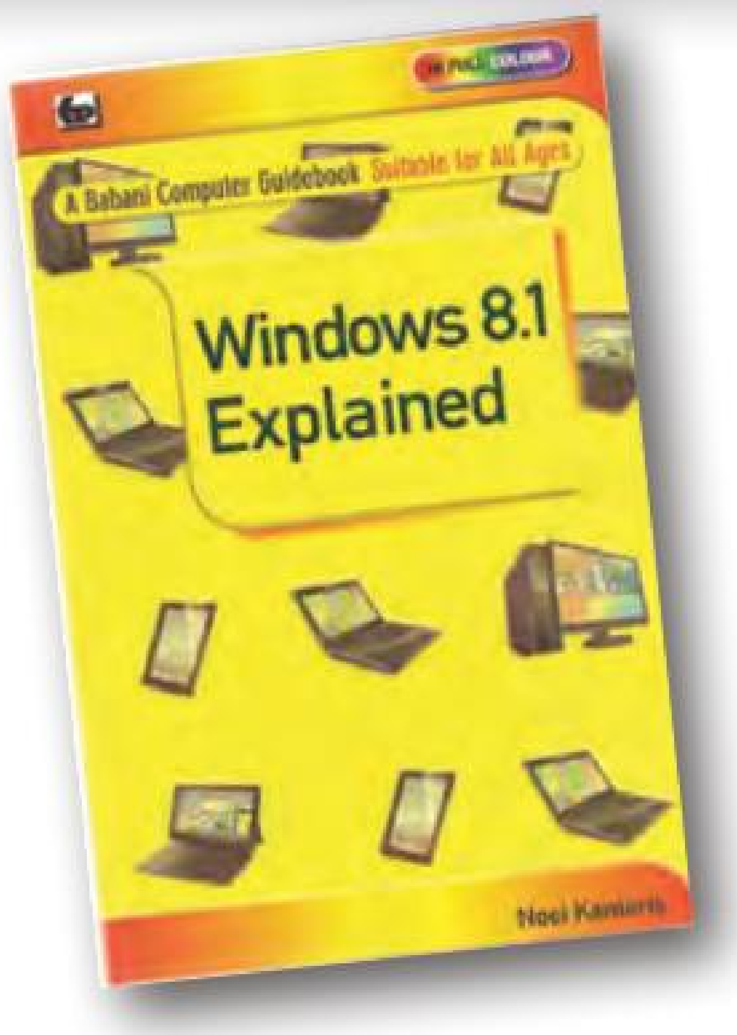

WINDOWS 8.1 EXPLAINED

Windows 8.1 is the latest version of Microsoft's operating system. It is installed on all new Windows Desktop. Laptop and X86 tablet computers and is also available as a free upgrade. Whether you choose to use the touch screen Tile interface or the mouse operated Desktop interface, a good working knowledge of the operating system is essential to get the most from your computer and this book will help you to do just that.

The book applies to Windows 8.1, Windows 8.1 Pro and the vast majority of Windows 8.1 Enterprise. Also parts of the book should be applicable to windows RT 8.1 which is built on the same foundation as Windows 8.1 but is a restricted version designed specifically for ARM tablets.

Among the many topic covered are: An overview of the Tile Interface, Desktop, Taskbar, Tray Notification Area, Charms bar and running Apps; managing Windows settings, personalising your PC and creating User Accounts; using the Desktop File Explorer, SkyDive, Internet Explorer and the E-mail App; working with and organising digital photographs, using Media Player to play and store music and to burn CDs and installing Media Center to play DVDs; connecting to wireless networks, setting up a HomeGroup, sharing a printer and networked PCs; using mobility tools to keep your laptop running while away from home; accessibility features should you have dexterity or eyesight problems; keeping your computer healthy and backing up important files; And much more besides…..

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A Babani Computer Guidebook Suitable for All Ages
Kindle Fire HDX Explained
Noel Kantaris

KINDLE FIRE HDX EXPLAINED

This book is written to help users get to grips, quickly and easily, with the amazing Kindle Fire HDX tablet. You will be guided through the configuration and use of the Kindle Fire HDXs facilities and functions. This book was written using the 7" HDX but it is also applicable to the 8.9" model.

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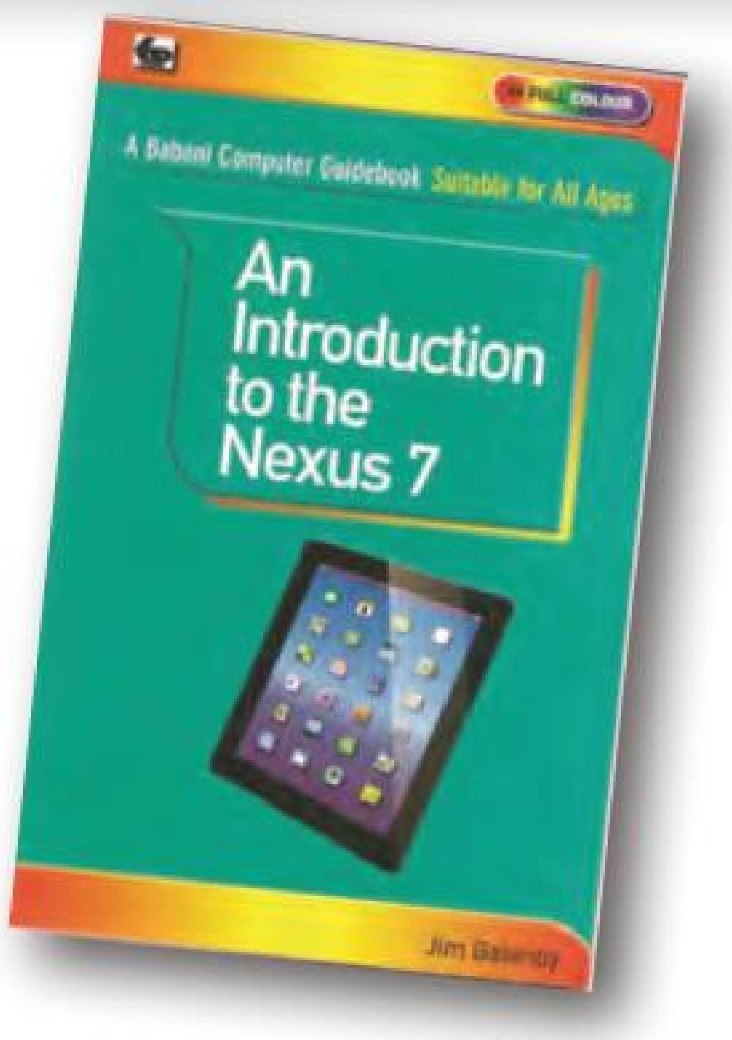
A Babani Computer Guidebook Suitable for All Ages
An Introduction to the Nexus 7
Jim Gatenby

AN INTRODUCTION TO THE NEXUS 7

This book is intended for the new user of the Nexus 7, although much of it will also apply to the Nexus 10. It is easy to understand being written in plain English and avoiding technical jargon wherever possible.

Among the many useful topics covered are: An overview of the main features of the Nexus 7; setting up the Nexus 7; charging the battery; connecting to the Internet and signing up for Gmail; touch-screen operation and navigating around the various screens; installing Apps from the Google Play Store; setting a password and other precautions to keep your files safe; connecting accessories such as a USB Drive, mouse and keyboard; enjoying entertainment such as eBooks, games, music and videos; searching the Internet, including speaking in keywords; using e-mail, Skype and social networking; installing the free Google Drive app to save your documents in the cloud; using Google Docs free word processing and spreadsheet software; printing a document using Google Cloud Print, Exporting Nexus 7 files to laptop and desktop computers; and much more besides….

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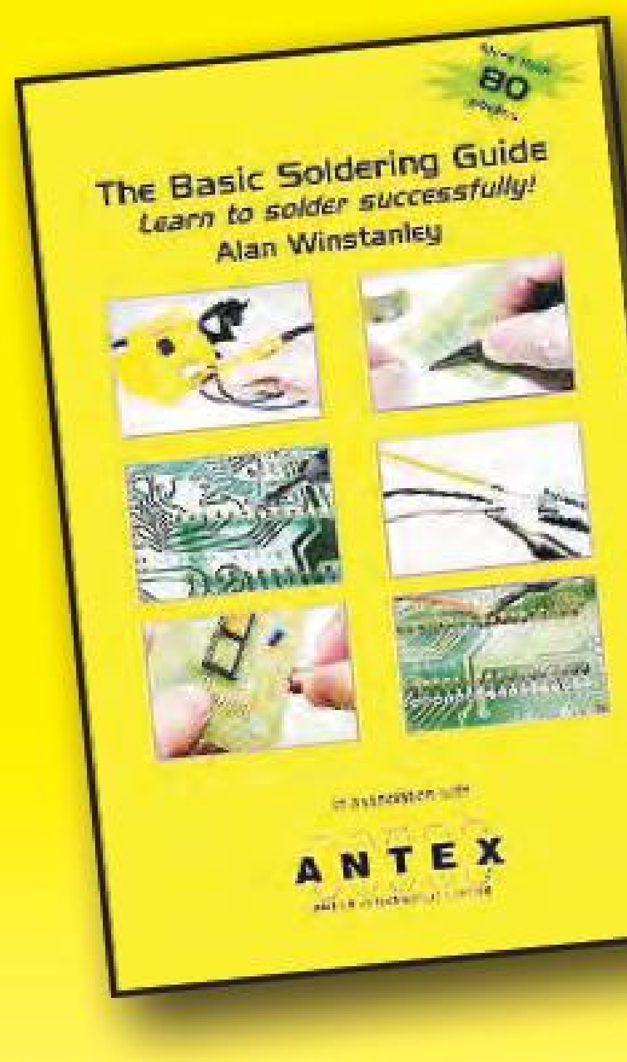

THE BASIC SOLDERING GUIDE HANDBOOK

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The No.1 resource to learn all the basic aspects of electronics soldering by hand.

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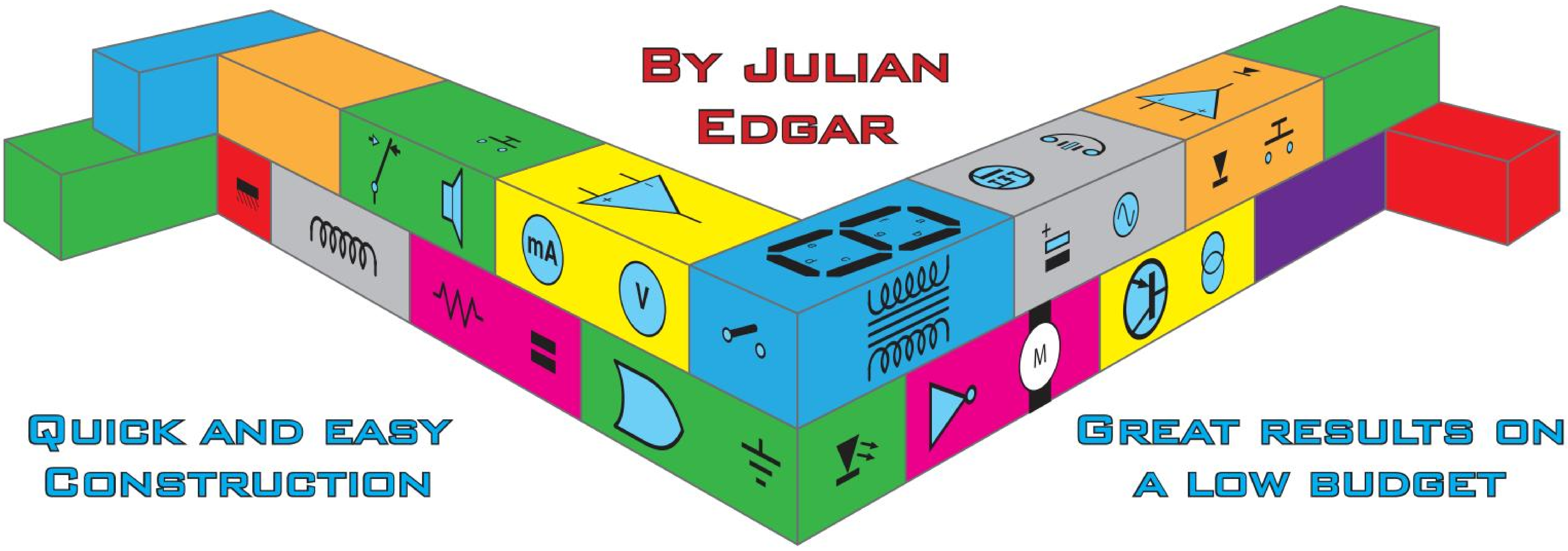
86 Pages **Order code AW1** **£9.99**

ELECTRONIC BUILDING BLOCKS



BY JULIAN EDGAR

QUICK AND EASY CONSTRUCTION

GREAT RESULTS ON A LOW BUDGET

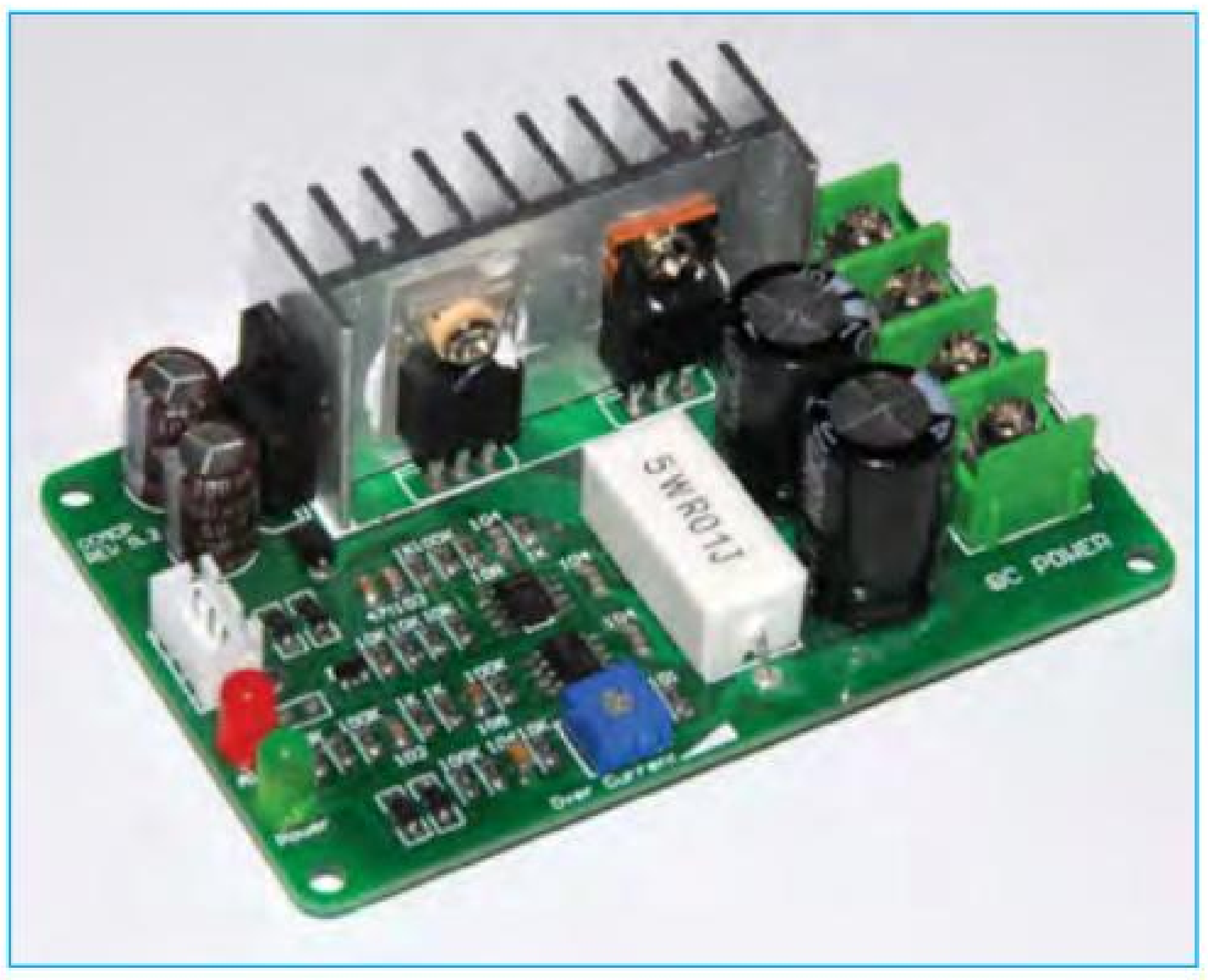
6A/24V POWER SUPPLY

Large complex projects are fun, but they take time and can be expensive. Sometimes you just want a quick result at low cost. That's where this series of *Electronic Building Blocks* fits in. We use 'cheap as chips' components bought online to get you where you want to be... FAST! They represent the best value we can find in today's electronics marketplace!

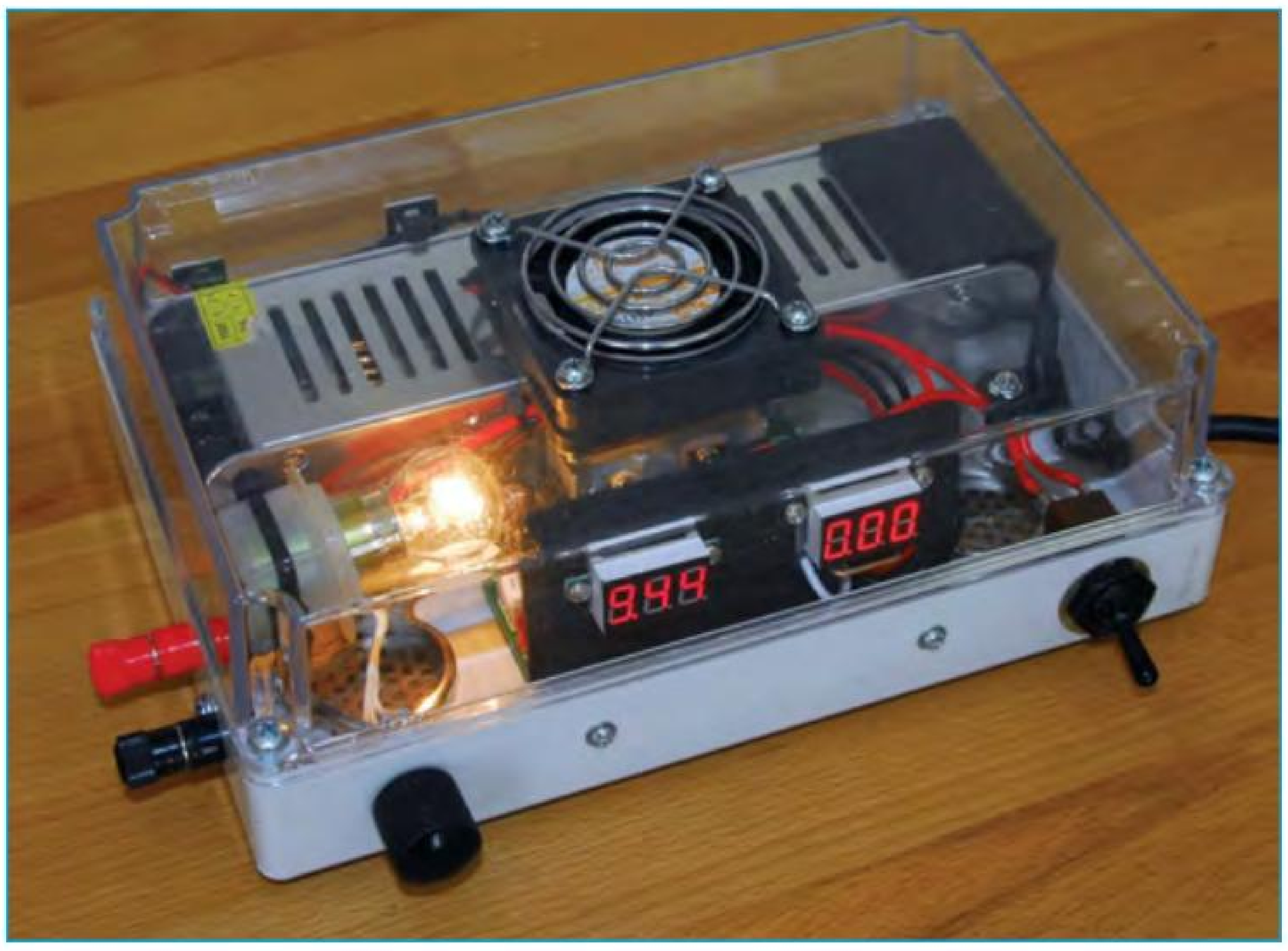
Here's a fantastic project that's so cheap it's unbelievable – a variable power supply that can supply up to 6A at 24V, has multiple overload protection systems and features digital displays for both voltage and current. Depending on the box you choose to put it in, and how you source some parts like nuts and bolts and a power cord, it will cost you from just £20!

Starting points – PWM board

The heart of the power supply is a DC motor speed controller board. As you probably know, a DC motor speed controller is a PWM (pulse-width modulation) device that can output a variable-duty-cycle signal, thus altering the average output voltage. We aren't using it to control a motor (although of course you could connect a motor to the power supply) but instead to provide the variable output voltage. The module is called: 'PWM DC Motor Speed Controller 12V/24V/36V 15A Controller Overload Stall Overcurrent' and costs just £7 delivered. (At the time of writing, look for eBay item 172336496727.)



This pre-built variable PWM module is the heart of the power supply. It features a remote-mounted adjustment pot and over-current protection. This module works very well – ensure that the one you buy looks identical.



Depending on how you source parts like the box and hardware, this power supply can cost you less than £20, yet it has an output of 6A at up to 24V, and features meters displaying voltage and current.

This board is being under-rated for our power supply application – a wise move as these boards often run quite hot. It has over-current protection built in. If the current exceeds the limit, the red LED lights and the output is automatically turned off. To reset the board, you need to switch power off and then back on again. This over-current limit can be set with an on-board pot – clockwise rotation of the pot raises the limit. The PWM board comes with a remote-mounted pot to control the output voltage.

Supplying the supply

Supplying the PWM board is a general propose 200W SMPS (switch-mode power supply). It is called 'IP20 AC220V To DC24V 200W Switching Power Supply Driver Adapter' and costs just £14.40, again delivered.

This power supply has an adjustable output pot that can fine-tune the output to 24V. As with the PWM module, this unit is protected against over-current – if tripped, this limiter drops output voltage and cycles its green power LED (visible at the output end of the box). I found that at some combinations of load and voltage it was shutting down at 6A, rather than the advertised 8A, which is why I've rated this power supply at 6A. (At the time of writing, look for eBay item 182249724363.)

This prebuilt switch-mode power supply powers our unit. It's claimed to deliver 8A at 24V, but we found it happier at about 6A maximum – still pretty good!

LED meters for voltage and current are positioned to 'see' through the clear lid of the box. The meters are mounted on a piece of scrap plastic. Taking this approach is much easier than cutting mounting holes for meters that use bezels.

Best price tip

Note, although the above components are available on eBay, better pricing is available at **www.banggood.com**, where I bought my items. You should be able to find the PWM module for about a fiver and the SMPS for around £11.

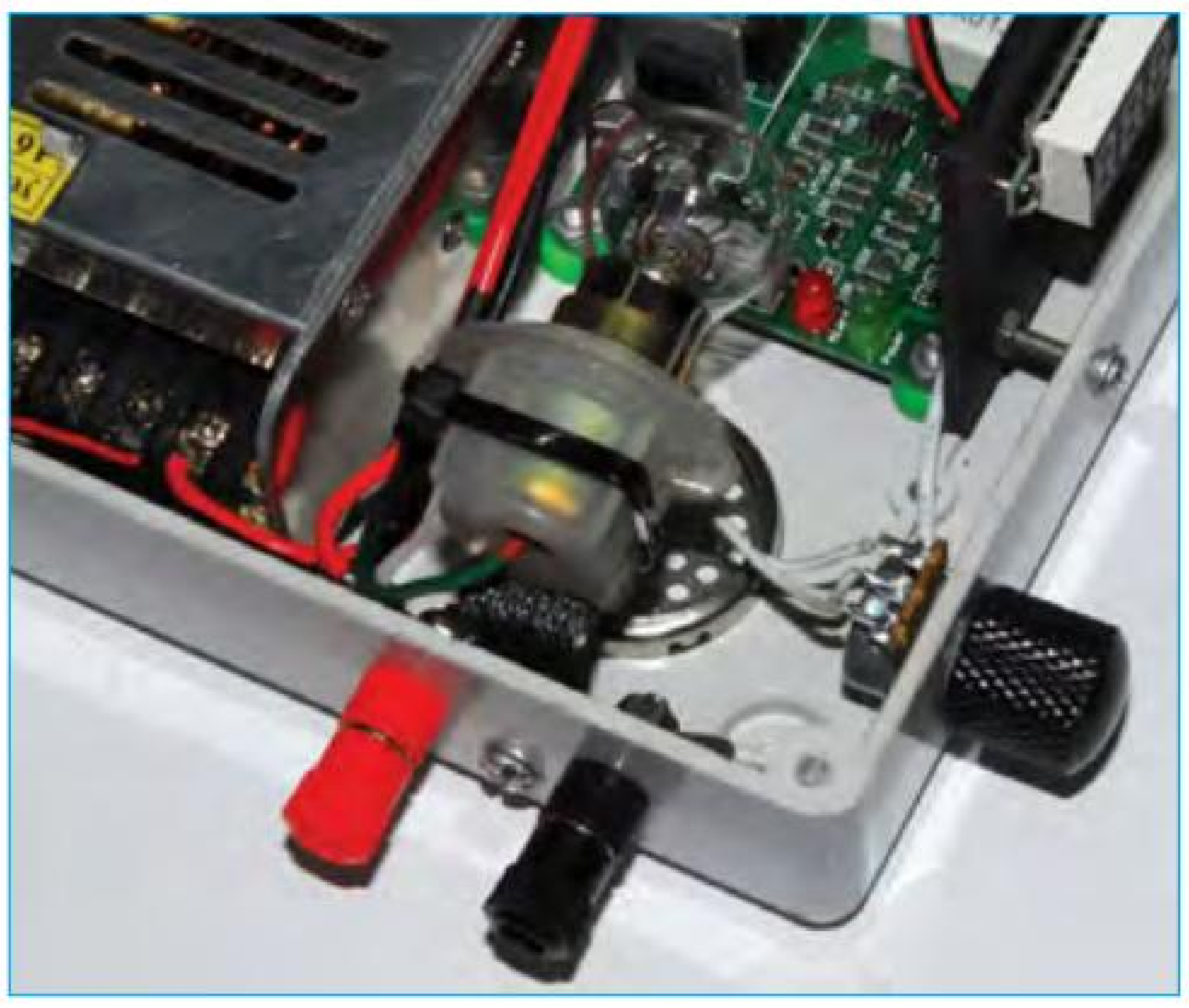
Meters

The LED meters for current and voltage are the 'bare bones' type, where the meters are not mounted in cases. This drops their price even further over other types. The ammeter, that incorporates an on-board shunt and can read to 10A, costs under £3, while the voltmeter cost £1. To find them search for '0.36" DC Amp Ammeter 10A Red LED Digital Current Panel Amperes Meter Board NEW' and 'Mini Red LED Panel Voltage Meter 3-Digital Adjustment Voltmeter~WY', respectively. (At the time of writing, for the ammeter look for eBay item 371648567535; and for the voltmeter, eBay item 262607265587.)

For my power supply, the PWM module, SMPS and meters were the only parts I bought new. The 24V fan, fan guard, switch, power cord, vents, output binding posts, box and hardware I already had. You probably also have some of these parts sitting on the shelf.

Simplest approach

At its simplest, all you need to do to build the power supply is:



The output is via two binding posts that also take banana plugs. Note also the incandescent light bulb that acts as an inbuilt permanent load, allowing the unit to provide better voltage regulation.

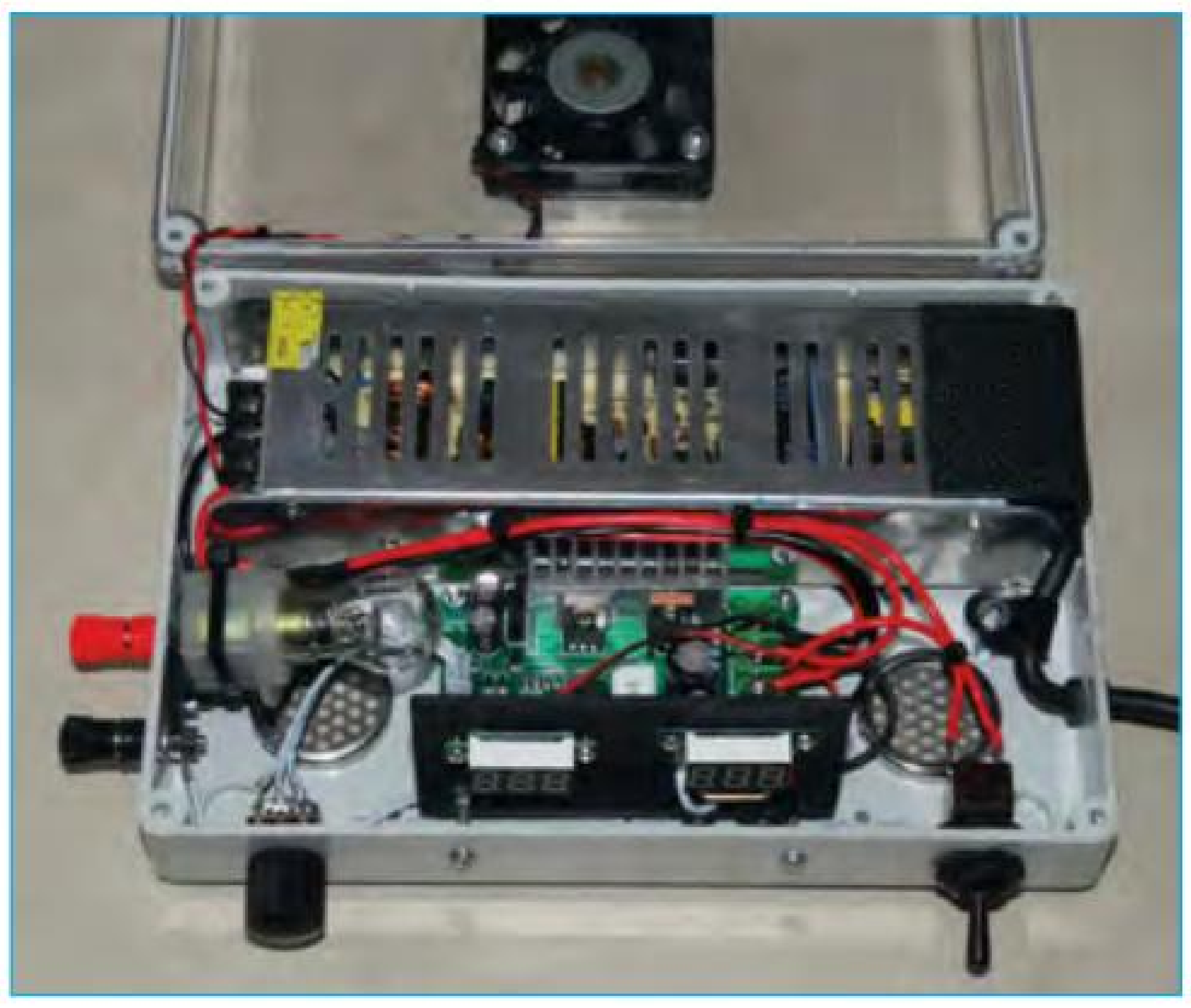
1. Mount the PWM board, SMPS and meters in a suitable box.
2. Wire a mains cable to the SMPS. **You must use an earthed plug and cable, and you should place a shield over the exposed mains connections once this wiring has been completed. You should also anchor the mains cable so that it cannot have its connections pulled out**.
3. Connect the output of the SMPS to the input of the PWM module. The inputs on this module are called 'DC power' and have a marked polarity that you must observe.
4. Wire the voltmeter across the output of the PWM module – it is powered by the supply it is reading. In use, it works down to less than a volt.
5. Wire the ammeter into place. In the one I bought, there were two thin wires to power the ammeter (red and black) and two thick wires (white and black) for the high current. Connect the thin red wire to +24V, but leave the thin black wire disconnected. The thick black wire from the ammeter goes to the negative output of the PWM module, and the thick white wire connects to the negative output binding post of the power supply. The positive binding post of the power supply connects, via a switch, to the positive output of the PWM module.

In this form, the power supply will run happily, albeit, a bit warm at times.

Connections for mains power (top right) should be covered by an insulating shield, as shown here.

Improvements

In the form described above, the voltage regulation can at times be a little less than optimal. For example, the power supply may show 15V on its display and then when you add a load, it drops to 9V. But if you then add another load, you'll find the voltage regulation is quite good – the voltage drops only very little (eg, less than a tenth of a volt) with the second load. The problem is that the PWM module 'expects' to see a load all the time – so why not give it one?



The top view with the cover off. The fan mounts in the cover. Note the two vents provided in the base of the box to supply air to the fan.

I initially used a 470Ω, 5W resistor across the PWM module's output, and that improved the on/off load voltage regulation considerably. But then I thought – why waste power in heat… when it could produce light? So I replaced the resistor with a 24V, 18W incandescent light bulb I had floating around. This gives a nominally 0.75A load at 24V, and both improves the regulation and adds satisfactory bling! If that's over the top, use a lower wattage 24V bulb – or go back to using a resistor.

Running continuously at maximum output, both the SMPS and the PWM board can get warm – plus, in my case, the added heat of the incandescent bulb. I chose to mount a salvaged 24V fan in the top of the box and run it all the time. You could use a temperature switch or manual switch to operate the fan. Some vents were mounted in the bottom of the box to supply the air being extracted by the fan. With the fan spinning, the unit runs quite cool, even at continuous high load.

Next month

In February's issue we will look at a fantastic *Four Channel Car Sound Amplifier* with a maximum output of 68W × 4 = 272W, ensuring plenty of volume and punchy bass! You definitely do not want to miss the next super *Electronic Building Block* article!

PCB SERVICE

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Basic printed circuit boards for most recent *EPE* constructional projects are available from the *PCB Service*, see list. These are fabricated in glass fibre, and are drilled and roller tinned, but all holes are a standard size. They are not silk-screened, nor do they have solder resist. Double-sided boards are **NOT plated through hole** and will require 'vias' and some components soldering to both sides. **NOTE: PCBs from the July 2013 issue with eight digit codes** have silk screen overlays and, where applicable, are double-sided, plated through-hole, with solder masks, they are similar to the photos in the relevent project articles.

All prices include VAT and postage and packing. Add £2 per board for airmail outside of Europe. Remittances should be sent to **The PCB Service, Everyday Practical Electronics, Wimborne Publishing Ltd., 113 Lynwood Drive, Merley, Wimborne, Dorset BH21 1UU. Tel: 01202 880299; Fax 01202 843233; Email: orders@epemag.wimborne.co.uk. On-line Shop: www.epemag.com**. Cheques should be crossed and made payable to *Everyday Practical Electronics* **(Payment in £ sterling only)**.

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For editorial address and phone numbers see page 7

Next Month

Content may be subject to change

Solar MPPT Charger and Lighting Controller – Part 1

This MPPT charger/light controller will work with 12V or 24V solar panels to charge a 12V or 24V lead-acid or lithium iron phosphate battery. You can then use the battery to run 12V DC lighting or a 12V/24V 230VAC inverter to run lighting or other loads.

High-performance stereo valve preamplifier – Part 2

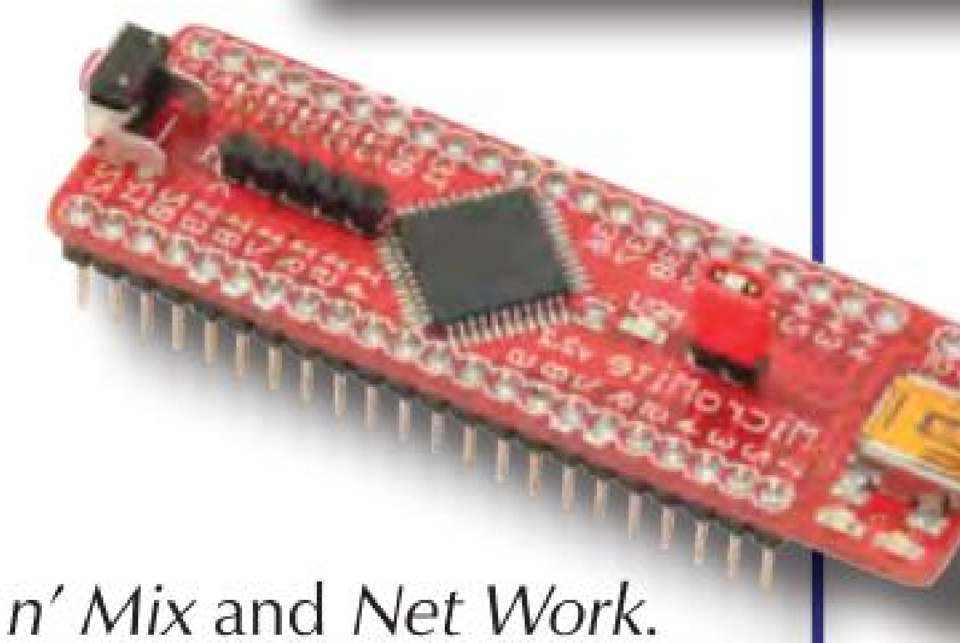
Having described how our new stereo valve preamp works and how to put the PCB together, now it's time to build the custom-designed case. This houses the PCB so that you can see all the components but can't touch the high-voltage sections.

Check your turntable's speed with this white LED strobe

So you have dragged out the old turntable and are playing vinyl records again. Good! But how do you know that the turntable speed is correct? The old way to do it was to use a circular disc with strobe markings, but that does not necessarily work these days. Why not? Find out next month and build our solution!

High Visibility 6-Digit LED GPS Clock – Part 2

Last month, we introduced our GPS high-visibility 6-digit LED clock. We want to emphasise its main feature: it automatically changes time zones as you travel – this is important if you are cruising on a yacht or just touring the world. This second article provides all the information you need to build and use the clock.



Meet the mighty Micromite – Part 1

The Micromite is an amazing device. A low-cost microcontroller programmed in a Microsoft-compatible version of BASIC with floating point, arrays and extensive string handling. Cheap, powerful and easy to use – you're going to love it!

PLUS!

All your favourite regular columns from *Audio Out* and *Circuit Surgery* to *Electronic Building Blocks*, *PIC n' Mix* and *Net Work*.

FEBRUARY '17 ISSUE ON SALE 5 JANUARY 2017

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Development Tool of the Month!

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Overview:

The MPLAB Xpress Evaluation Board offers seamless integration with Microchip's software tool chain, including the MPLAB Xpress Cloud-Based IDE. MPLAB Xpress is an online development environment that contains the most popular features of our award-winning MPLAB® X IDE. This simplified and streamlined application is a faithful reproduction of our desktop-based program, which allows you to easily transition between the two environments. The centerpiece of the board is the PIC16F18855 MCU, an 8-bit device with the unique combination of low power consumption, performance to handle almost any application task and on-chip peripherals that enable you to control your system with a minimal amount of code.

Key Features:

- Compact, credit card-sized footprint offers flexibility during the prototyping phase
- On-board PIC16F18855 MCU supports a wide range of applications
- MikroBus Expansion Header with over 180 off-the-shelf options for adding functionality to your design
- Integrated drag-and-drop programmer with USB interface—no drivers required
- Analog potentiometer and push-button switches for user input
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- Measure leakage current.
- Measure MOSFET thresholds.
- Measure LED voltages.

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Just a few example screen shots:

PNP Germanium Transistor ↓
RED GREEN BLUE Emit Coll Base ↓
Current gain hFE=67 ↓
Test current IC=2.50mA ↓
Base-Emitter V VBE=0.293V ↓
Test current IB=4.981mA ↓
Leakage current IC=0.027mA ↓

NPN Silicon Transistor ↓
RED GREEN BLUE Base Emit Coll ↓
Current gain hFE=117 ↓
Test current IC=2.50mA ↓
Base-Emitter V VBE=0.711V ↓
Test current IB=4.583mA ↓
Leakage current IC=0.000mA ↓

PNP Darlington Transistor ↓
RED GREEN BLUE Emit Base Coll ↓
Diode protection between C-E ↓
Current gain hFE=9124 ↓
Test current IC=2.50mA ↓
Base-Emitter V VBE=1.321V ↓
Test current IB=3.720mA ↓
Leakage current IC=0.000mA ↓

Enhancement mode N-Ch MOSFET ↓
RED GREEN BLUE Gate Drn Srce ↓
Gate Threshold VGS=3.47V ↓
Test current ID=2.50mA ↓

Diode or diode junction(s) ↓
RED GREEN BLUE Anod Cath ↓
Forward voltage VF=0.694V ↓
Test current IF=4.663mA ↓

Three terminal bicolour LED ↓
Pinout for D1 ↓
RED GREEN BLUE Anod Cath ↓
Forward voltage D1 VF=1.983V ↓
Test current D1 IF=3.223mA ↓
Pinout for D2 ↓
RED GREEN BLUE Anod Cath ↓
Forward voltage D2 VF=1.927V ↓
Test current D2 IF=3.281V ↓

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